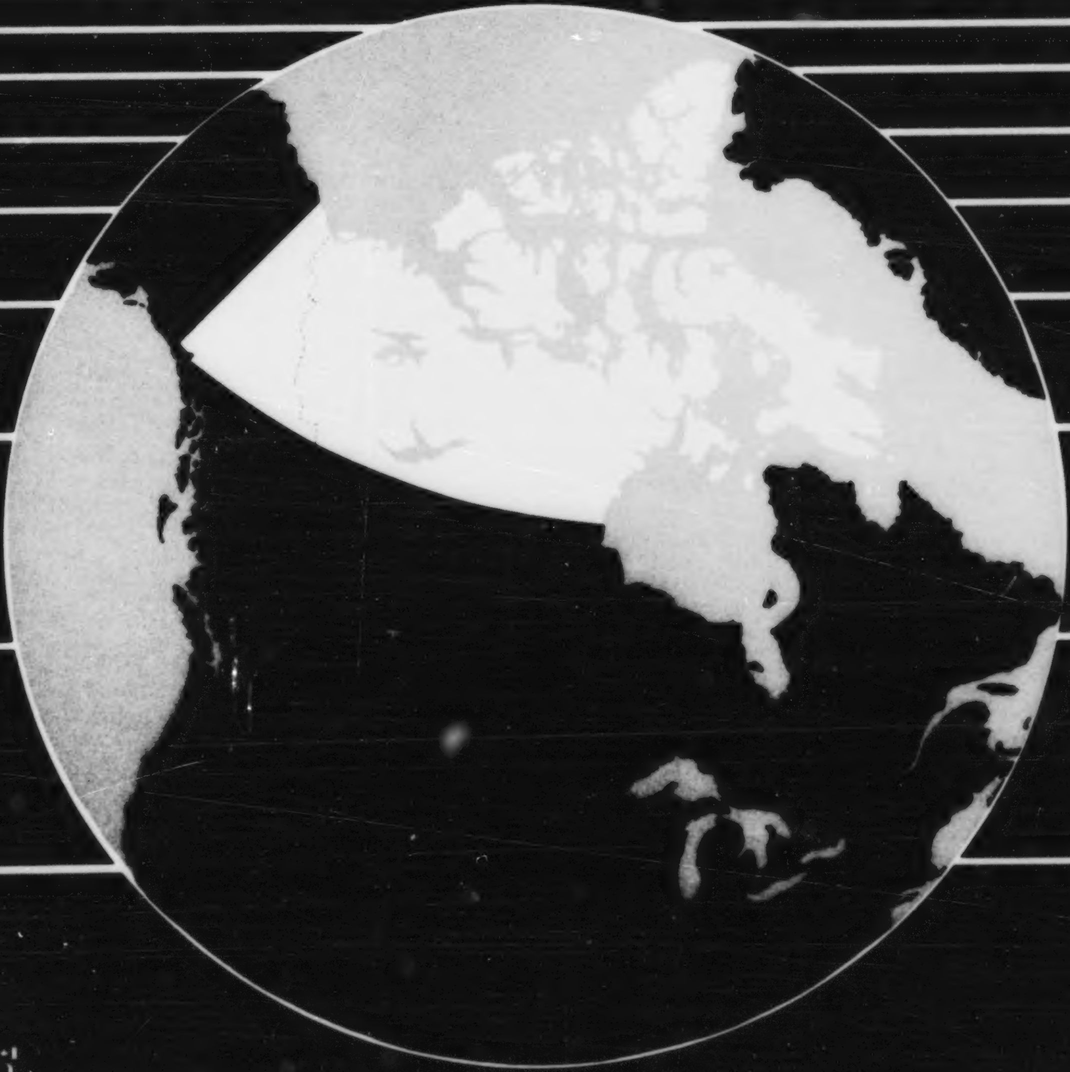
Environmental Studies No. 50

Bowhead Whale Food Availability Characteristics in the Southern Beaufort Sea: 1985 and 1986



Canada

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Bowhead Whale Food Availability Characteristics in the Southern Beaufort Sea: 1985 and 1986

Northern Affairs Program

LGL Ltd.
Environmental Research Associates

Published under the authority of the
Hon. Bill McKnight, P.C., M.P.,
Minister of Indian Affairs and
Northern Development,
Ottawa, 1987.

QS-8407-000-EF-A1
Catalogue No. R71-19/50-1988E
ISBN 0-662-15935-7

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This Report was prepared under contract for the Northern Oil and Gas Action Program (NOGAP), Northern Environment Directorate, Natural Resources and Economic Development Branch, Department of Indian Affairs and Northern Development.

The views, conclusions and recommendations expressed herein are those of the authors and not necessarily those of the Department.

Indian and Northern Affairs Canada
Affaires indiennes et du Nord Canada

PREFACE

This volume presents the results of two summer-time, ship-based sampling programs; one off the Yukon coast in 1985 and the other, more extensive, covering most of the southern Beaufort Sea in 1986. The studies include data on zooplankton composition, concentration and caloric value and include characterizations of physical and oceanographic conditions. All data are related to bowhead whale distribution and the studies address the natural factors (as opposed to industrial) which may affect that distribution.

The two reports included in this volume are, in order of appearance:

1. Bradstreet, M.S.W., Thomson, D.H. and D.B. Fissel. 1987. Zooplankton and bowhead whale feeding in the Canadian Beaufort Sea, 1986. Rep. by LGL Limited, King City, Ontario, for Canada Department of Indian Affairs and Northern Development, Ottawa. 204 p.

2. Bradstreet, M.S.W. and D.B. Fissel. 1986. Zooplankton of a bowhead whale feeding area off the Yukon coast in August, 1985. Rep. by LGL Limited, King City, Ontario, for Canada Department of Indian Affairs and Northern Development, Ottawa. 155 p.

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ABSTRACT

This Volume, consisting of two separate reports, addresses the natural (as opposed to industrial) factors which may affect bowhead whale (Balaena mysticetus) distribution in the southern Beaufort Sea. The focus of the study is on the distribution of zooplankton available to bowhead whales during the important summer period in which most, if not all, their annual food supply is probably consumed. The physical and oceanographic factors which influence zooplankton distribution are thoroughly examined. Results are presented from two ship-based sampling programs; one off the Yukon Coast in 1985 and the other, more extensive, covering most of the southern Beaufort Sea in 1986.

Data suggest that it is not so much the total biomass, but more the concentration of zooplankton into dense subsurface layers that preconditions an area for bowhead feeding. It appears that high zooplankton biomass tends to occur near areas, such as off the Yukon coast, where persistent easterly, or periodic but strong southerly winds induce upwelling of Arctic Ocean water. Convergence along frontal zones forming between the Arctic Ocean water and the "diffuse" or "intense" Mackenzie River plume waters then serves to concentrate zooplankton into large elongated patches forming on the inclined, subsurface frontal interfaces. The frontal features are well depicted in the satellite imagery presented.

Zooplankton concentrations are shown to be highest near feeding whales where net samples indicated values in excess of 1 g/m^3, reaching maximum site-specific values of 2.3 g/m^3 (1985) and 1.5 g/m^3 (1986). Detection in both years was aided by a 200 kHz narrow-beam echo sounder mounted near the sea surface. However, in 1986 this single frequency system was found to be limiting in the presence of other reflectors (biological or non-biological) in the water column and so could not reliably detect high-concentration zooplankton patches that may well have been present in areas where whales were not feeding.

Waters of Mackenzie plume influence, but apparently devoid of any upwelling or strong frontal dynamics did not appear to support feeding whales. During 1986 this area included much of the so-called "industrial zone". In 1986 mean zooplankton biomass in waters less than 40m deep did not differ significantly between areas where whales were feeding and where they were not. But it is assumed, with some supporting evidence, that Mackenzie-influenced waters contain fewer, if any, of the dense zooplankton patches whales are known to exploit.

The hypothesis that the endangered bowhead whale is deprived, through industrial disturbance, from feeding in large areas of the Beaufort Sea is not addressed in this volume. However, the reports amass a great deal of evidence to suggest that bowheads feed only in areas of very high zooplankton concentration. In 1986, such areas may not have occurred in the industrial zone.

RÉSUMÉ

Ce volume, qui se compose de deux rapports distincts, porte sur les facteurs naturels (par opposition aux facteurs industriels) qui peuvent influer sur la répartition de la baleine boréale (Balaena mysticetus) dans le sud de la mer de Beaufort. L'étude s'intéresse principalement à la répartition du zooplancton dont se nourrit la baleine boréale pendant la saison estivale, si importante pour cette baleine, car c'est au cours de l'été qu'elle consomme la plus grande partie, sinon la totalité, de sa nourriture pour l'année. Les facteurs physiques et océanographiques qui exercent une action sur la répartition du zooplancton sont soigneusement examinés. Les résultats sont tirés de deux séries d'échantillonnages réalisés par navire: une première série effectuée au large de la côte du Yukon en 1985 et une deuxième, plus exhaustive, effectuée en 1986 et couvrant la plus grande partie du sud de la mer de Beaufort.

Les données semblent indiquer que, plus que la biomasse totale, la concentration du zooplancton en couches denses sous la surface détermine les aires d'alimentation de la baleine boréale. On trouve des biomasses zooplanctoniques importantes près des zones où, comme au large de la côte du Yukon, des vents d'est soufflent de façon continue ou des vents du sud périodiques, mais puissants, provoquent des remontées d'eau plus profonde de l'océan Arctique. La convergence se formant le long des zones frontales entre les eaux de l'océan Arctique et les eaux "diffuses" ou "intenses" du panache du fleuve Mackenzie concentre ensuite le zooplancton en grandes masses allongées sur les interfaces frontales inclinées, sous la surface. Les caractéristiques des zones frontales sont bien visibles sur les images satellites présentées dans le volume.

On observe les plus fortes concentrations zooplanctoniques près des aires d'alimentation des baleines, où l'échantillonnage a révélé une concentration nette de plus de 1 g/m^3, avec en des endroits précis des valeurs maximales de 2,3 g/m^3 (1985) et 1,5 g/m^3 (1986). Au cours des deux années d'échantillonnage, la détection a été effectuée au moyen d'un sondeur à écho à faisceau étroit fonctionnant à une fréquence de 200 kHz et installé près de la surface de la mer. Toutefois, en 1986, on a constaté que la sensibilité de ce système à fréquence unique était limitée en présence d'autres réflecteurs (biologiques ou non) dans la colonne d'eau et que, par conséquent, il ne pouvait détecter efficacement certaines zones de haute densité zooplanctonique qui auraient pu être présentes dans des régions où les baleines n'allaient pas se nourrir.

Les eaux subissant l'influence du panache du fleuve Mackenzie, mais où ne se manifestent pas de remontées d'eau profonde et de zones frontales bien définies ne semblent pas servir d'aire d'alimentation aux baleines. Au cours de 1986, ces eaux incluaient une bonne partie de la zone dite industrielle. Dans les eaux de moins de 40 m de profondeur, la biomasse zooplanctonique moyenne en 1986 ne différait pas de façon significative entre les aires d'alimentation des baleines et les autres aires. Mais l'on présume, avec un certain nombre de données à l'appui, que les eaux subissant l'influence du fleuve Mackenzie contiennent moins - si jamais elles en contiennent - de ces zones à haute densité zooplanctonique qu'exploitent les baleines pour leur alimentation.

On n'a pas examineé, dans le cadre de cette étude, l'hypothèse selon laquelle la baleine boréale, qui est qualifiée d'espèce menacée, a été privée de grandes aires d'alimentation dans la mer de Beaufort à cause de l'activité industrielle. Toutefois, un grand nombre de données présentées dans les rapports semblent indiquer que les baleines boréales ne se nourrissent que dans les aires de grande densité zooplanctonique. Or, il se peut qu'en 1986, la zone industrielle ait été complètement dépourvue de telles aires de haute densité.

ZOOPLANKTON AND BOWHEAD WHALE FEEDING IN THE CANADIAN BEAUFORT SEA, 1986

by

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December 1987

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INTRODUCTION

Bowhead whales, Balaena mysticetus, winter in the Bering Sea and annually migrate to summering areas in the Beaufort Sea and Amundsen Gulf (Fraker and Bockstoce 1980). It has been assumed that bowheads, like other mysticete whales, feed primarily during the summer. If so, annual migrations are probably undertaken to reach preferred feeding areas. This would imply that summering areas are rich in food, and important to the whales that travel a round-trip distance of several thousand kilometres to feed in those areas.

Bowhead whales generally arrive in Canadian waters in June. At that time they are present in the extreme eastern Beaufort Sea and Amundsen Gulf area, having traveled from Point Barrow, Alaska, to Banks Island through offshore waters where there are cracks and leads in the ice (Fraker 1979). By early to mid August, bowheads are present inshore along the Mackenzie Delta and Yukon coastlines, and they remain in those areas until at least early September (Richardson et al. 1987a). By early to mid September, some bowheads begin to move westward toward and into the Alaskan Beaufort Sea, but other individuals remain in the Canadian Beaufort Sea until late September or early October.

There are no stomach content data on the types or quantities of food consumed by bowheads that summer in the Canadian Beaufort Sea and Amundsen Gulf. During fall migration past Kaktovik, Alaska (120 km west of the Yukon/Alaska border), bowhead whales are hunted by native people; food samples have been obtained from the stomachs of the harvested animals. Lowry and Frost (1984) reported the diets of eight bowheads taken at Kaktovik during the autumns of 1979-82 as 66% copepods, 31% euphausiids and minor amounts of mysids, hyperiid and gammarid amphipods, other invertebrates and fish (percentages determined from total sample volumes). Lowry and Frost concluded that during the fall, bowhead feeding is directed primarily at organisms in the water column. This is apparently also true earlier in the summer, when the whales are in the Canadian Beaufort Sea. Würsig et al. (1985) described three modes of apparent feeding behaviour: skim feeding at the surface, feeding near the bottom, and feeding in the water column. Although surface feeding and near bottom feeding were easier to document, Würsig et al. (1985) suspected that water column feeding was the most common feeding mode.

We have only indirect evidence about bowhead feeding habits in the Canadian Beaufort Sea. Griffiths and Buchanan (1982) sampled near feeding bowheads north of Richards Island in 1980-81, and Bradstreet and Fissel (1986) sampled near feeding bowheads close to the Yukon coast in 1985. In both cases, biomass of copepods was higher in samples taken near feeding whales than in samples taken at some distance from the whales. However, species composition in samples taken near bowheads differed between the two studies. *Calanus hyperboreus* and *C. glacialis* were the dominant copepods in samples taken near whales that were feeding north of Richards Island. A smaller species, *Limnocalanus macrurus*, was the dominant copepod taken near feeding whales off the Yukon coast. *Limnocalanus macrurus* was also the dominant zooplankter in samples taken near feeding bowheads farther west, near the Alaska-Yukon border, in 1986 (Griffiths et al. 1987). The stomach of a bowhead harvested at Kaktovik, Alaska, in September 1986 contained *Limnocalanus* and other small copepods (Lowry et al. 1987).

There is considerable concern that industrial activities associated with hydrocarbon development in the Canadian Beaufort Sea may result in adverse environmental impacts to bowhead whales (LGL et al. 1984; ESL et al. 1986). Industrial activity in parts of the Canadian Beaufort Sea deep enough to be occupied by bowheads began in 1976. Bowheads were numerous in the zone of industrial activity in three of five years from 1976 to 1980, less common in 1981, and not common in any year from 1982 to 1986 (Richardson et al. 1985a, 1987a; Norton and Harwood 1986; Harwood and Norton 1986; Ford et al. in prep.).

One hypothesis that has been developed to account for this apparent change in distribution is that noise and disturbance are now excluding bowheads from the area of industrial activity (Richardson et al. 1985a, 1987a; ESL et al. 1986). However, there is much year-to-year variation in the distribution of whales outside as well as within the industrial zone. Assumed variations in food availability (i.e., variations in locations where zooplankton is sufficiently concentrated to be economic for the whales to exploit) might also account for the observed variation in bowhead distribution since industrial activity began. Although factors affecting zooplankton patchiness in the Beaufort Sea had not been studied directly before 1985, concentrations of zooplankton are probably controlled by oceanographic and meteorological factors that are variable and independent of industrial activity (Borstad 1985; Thomson et al. 1986). Thus, a second hypothesis that might explain part or all of the variability in whale distribution is that the bowheads may follow an annually varying food supply. It should be noted that these two hypotheses are not mutually exclusive. In the absence of disturbance, bowheads would be expected to occur in areas with exploitable food resources.

This study in 1986 and the one that preceded it in 1985 (Bradstreet and Fissel 1986) were designed to identify relationships between physical oceanography and zooplankton, and to help assess variation in food availability. Due to logistic constraints in 1985, it was not possible to sample zooplankton both along the Yukon coast and in the area of industrial activity. Many bowheads were present off the Yukon coast during the 1985 sampling in that area and useful information on the characteristics of bowhead feeding areas was obtained. In 1986 a large ship, the M.V. Arctic Ivik, was used, and the study was expanded to include the area of industrial activity north of the Mackenzie Delta as well as waters off the Yukon coast. During the 1986 fieldwork, the study area was further expanded to include an area off the eastern Tuktoyaktuk Peninsula (Fig. 1) when a large number of bowheads were sighted in this region by aerial surveyors. The 1986 study was conducted over a 12-day period from 28 August to 8 September.

The results of this study and those of Bradstreet and Fissel (1986) enable us to make some year-to-year (1985 vs. 1986) comparisons of zooplankton and physical oceanography off the Yukon coast, and to compare the zooplankton and physical oceanography of three regions in the Southeastern Beaufort Sea during 1986. The results of these two studies also can be compared with those of bowhead feeding studies conducted in August of 1980-81 in the area of industrial activity off the Mackenzie Delta (Griffiths and Buchanan 1982), and in September of 1985-86 in the eastern Alaskan Beaufort Sea (Richardson [ed.] 1987).

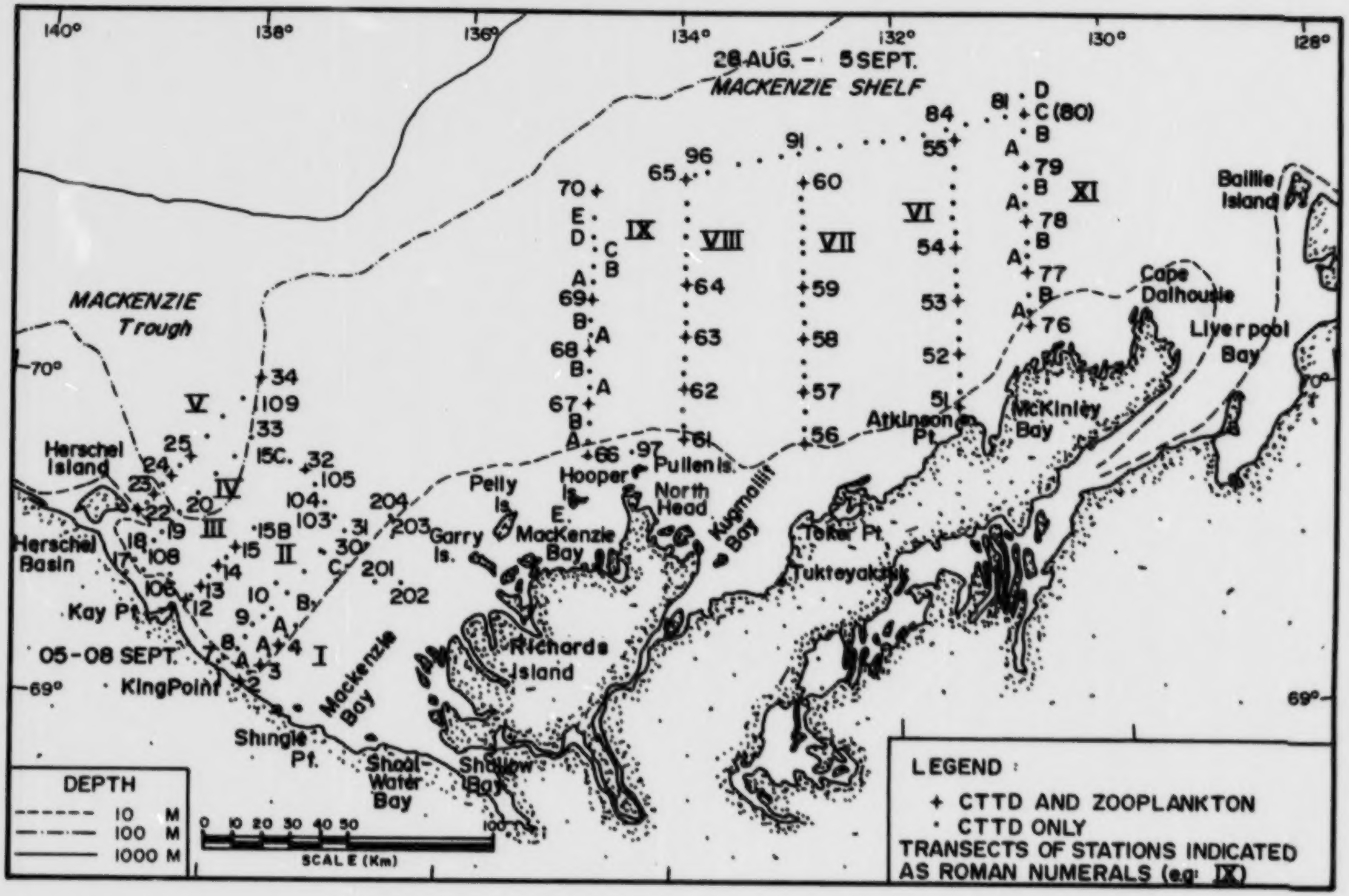
140°
138°
136°
134°
132°
130°
128°
70°
69°
28 AUG. - 5 SEPT.
MACKENZIE SHELF
MACKENZIE Trough
05-08 SEPT.
Herschel Island
Herschel Basin
Kay Pt.
King Point
Shingle Pt.
Mackenzie Bay
Shoal Water Bay
Shallow Bay
Garry Is.
Pelly Is.
Hooper Is.
Pullen Is.
North Head
MacKenzie Bay
Richards Island
Kugmallit Bay
Toker Pt.
Tuktoyaktuk
Atkinson Pt.
McKinley Bay
Cape Dalhousie
Liverpool Bay
Baillie Island
I
II
III
IV
V
VI
VII
VIII
IX
XI
DEPTH
10 M
100 M
1000 M
0 10 20 30 40 50 100
SCALE (Km)
LEGEND :
+ CTTD AND ZOOPLANKTON
· CTTD ONLY
TRANSECTS OF STATIONS INDICATED AS ROMAN NUMERALS (eg: IX)

Figure 1. Map of CTD-transmissiometer sampling locations.

During summer, the surface water in the southeastern Beaufort Sea can be divided into three broad categories (Fissel and Birch 1984; Borstad 1985; Thomson et al. 1986; Bradstreet and Fissel 1986):

Intense Plume Water.--This category includes areas where the surface layer has high temperature, high turbidity, and low salinity. In the study area, the intense plume is found adjacent to the Mackenzie River Delta. At the offshore boundary of the intense plume, there is a strong horizontal gradient (or front) where temperature and turbidity decrease considerably over distances of a few kilometres or less. The intense plume is a surface feature; typically it extends down to depths of 3 to 5 m, or to the bottom in the very shallow deltaic areas.

Diffuse Plume Water.--The influence of Mackenzie River water extends over a much larger surface area, well beyond the intense plume. Within this larger area, referred to as the diffuse plume, temperature and turbidity levels within the surface layer are moderately greater than in the cold, clear surface waters of the Arctic Ocean. The diffuse plume is not as homogeneous as the intense plume. Variations in water properties occur as local minima or maxima. Filaments and meanders of diffuse plume water protrude outward from the front marking the outer edge of the intense plume. Due to the variability within the zone and to the lower values of temperature and turbidity, it is often difficult to map the outer boundary of the diffuse plume unambiguously. The diffuse plume occurs as a thin surface layer, extending to depths ranging from 2 to 10 m. Cold, clear arctic water is found beneath the diffuse plume.

Arctic Water.--The remainder of the area has the cold and clear characteristics of Arctic Ocean water. Due to the preponderance of sea-ice within the area, surface temperatures are usually less than 1-2°C. (In years of extensive early clearing of sea-ice offshore, solar heating can cause warming of surface temperatures to 4-6°C.) The absence of particulate matter results in extremely low turbidity levels, typically equivalent to secchi depths of 10 m more. Arctic water occurs at the surface at locations distant from the Mackenzie River Delta, and can occur below the Mackenzie plume at locations much closer to the Delta.

The locations and movements of surface water types are largely determined by the wind (Thomson et al 1986). Wind may also cause nearshore upwelling and determine the distribution of sea ice during the open water season. Thomson et al. (1986) speculated that the location and intensity of the Mackenzie River plume was an important determinant of zooplankton standing crop and hence bowhead whale distributions. This study, like its predecessor (Bradstreet and Fissel 1986), stresses the integration of meteorological, physical oceanographic and biological data to explain variations in zooplankton standing crop and species composition, especially as they relate to bowhead feeding.

METHODS

Physical Oceanography Methods

Regional Sea-ice Patterns and Wind Conditions

Information on sea-ice conditions during the study was obtained from weekly charts prepared by Ice Central, Atmospheric Environment Service, Environment Canada.

Meteorological data were collected from coastal stations bordering the Beaufort Sea and aboard the M.V. Arctic Ivik. For the five coastal measurement sites, time series measurements of wind speed and direction, atmospheric pressure and air temperature were obtained from Arctic Weather Central of the Atmospheric Equipment Service (Table 1).

The meteorological data collected from the M.V. Arctic Ivik consisted of 5 minute averages of wind speed and direction, atmospheric pressure, temperature and humidity. These data were collected using a Campbell Scientific weather station with digital data storage onto cassette tape. The digital data were collected from 29 August to 7 September 1986. Wind speed and direction were measured from the forward mast of the ship about 22 m above sea level. Wind speed and direction were measured relative to ship, so computation of true wind speed and direction required measurement of the ship's speed and heading. These latter data were obtained at 3 h intervals, with the result that absolute wind data are available at 3 h intervals.

Table 1. Summary of meteorological sampling periods obtained for coastal locations.

Site	Period	Sampling Interval (h)	Missing Data
Komakuk	15 Aug 30 Sept	6	-
Herschel Island	1-30 Sept	3	18:00 1 Sept to 15:00 2 Sept; 00:00-09:00 3 Sept
King Point	15 Aug-15 Sept	3	-
Shingle Point	15 Aug-30 Sept	6	-
Tuktoyaktuk	15 Aug-15 Sept	1	06:00-12:00 GMT daily

Ship-Based Water Mass Data

Temperature-Salinity-Transmissivity Profiles.--A total of 176 vertical profiles of temperature, salinity and light transmissivity were obtained from 28 August to 8 September 1986 from the M.V. Arctic Ivik. The locations of oceanographic stations are plotted in Figure 1 and tabulated in Appendix 1. From 28 August to 3 September, sampling was conducted in the eastern half of the Canadian Beaufort Sea, on transects 6, 7, 8, 9 and 11. On 4 and 5 September, transect 8 stations were sampled a second time. Operations then shifted to the area off the Yukon coast and in Mackenzie Bay (transects 1 to 5, inclusive), which was sampled from 5 to 8 September.

The profile data were collected with the Institute of Ocean Sciences' Applied Microsystems model STD-12 system. The unit was equipped with a Sea Tech transmissiometer, operating over a 25 cm path length with 660 nm light source. The raw data, consisting of temperature, conductivity ratio, pressure and transmissivity, were stored in internal Random Access Memory (RAM) within the STD-12. Following data collection at each station, the RAM contents were transferred to floppy diskette through an Apple IIe microcomputer. The computer converted the data to engineering units: pressure in decibars (dbars), temperature in degrees Celsius (°C), transmissivity in percent. Salinity values were computed from the pressure, temperature and conductivity ratio data, using the Practical Salinity Scale 1978 (Lewis 1981) in psu, and written to floppy diskette in place of the conductivity ratio data. Computed values for sigma-t (or reduced density) and measurement depth were written to diskette as well. Plots and data listings of temperature, salinity and transmissivity were also generated immediately after each oceanographic station was sampled. According to the manufacturer, accuracies approaching 0.005 C° (temperature), 0.25 dbar (pressure), 0.010 mmho/cm and 0.02 psu (equivalent salinity) are attainable with a high level of sensor calibration.

Independent measurements of temperature and salinity were collected at some CTD stations. A reversing thermometer (estimated accuracy of 0.02 C°) was used to provide temperature measurements, while salinity was determined from subsequent laboratory analyses (accuracy of better than 0.02 psu) of in-situ water samples collected from oceanographic sampling bottles. Comparisons of the reversing thermometer with CTD-derived measurements are presented in Figure 2. Note that temperature comparisons obtained in the presence of significant vertical thermal gradients were discarded. The temperature comparisons exhibit a relatively high level of scatter, as indicated by the standard deviation of temperature differences being 0.09 C°s. The large degree of scatter arises from the use of non-concurrent temperature measurements collected at or near the surface, where natural variability in temperature is high. As the mean temperature difference is negligible (<0.01C°), in terms of the much larger standard deviations, no corrections were deemed necessary for the CTD temperature measurements. The accuracy of the temperature data obtained with the STD-12 is estimated to be better than ± 0.10 C°.

For the comparisons between CTD- and bottle-derived salinity measurements (excluding samples obtained in significant vertical gradients), the scatter is also large (mean ± standard deviation of salinity differences is -0.01 ± 0.21

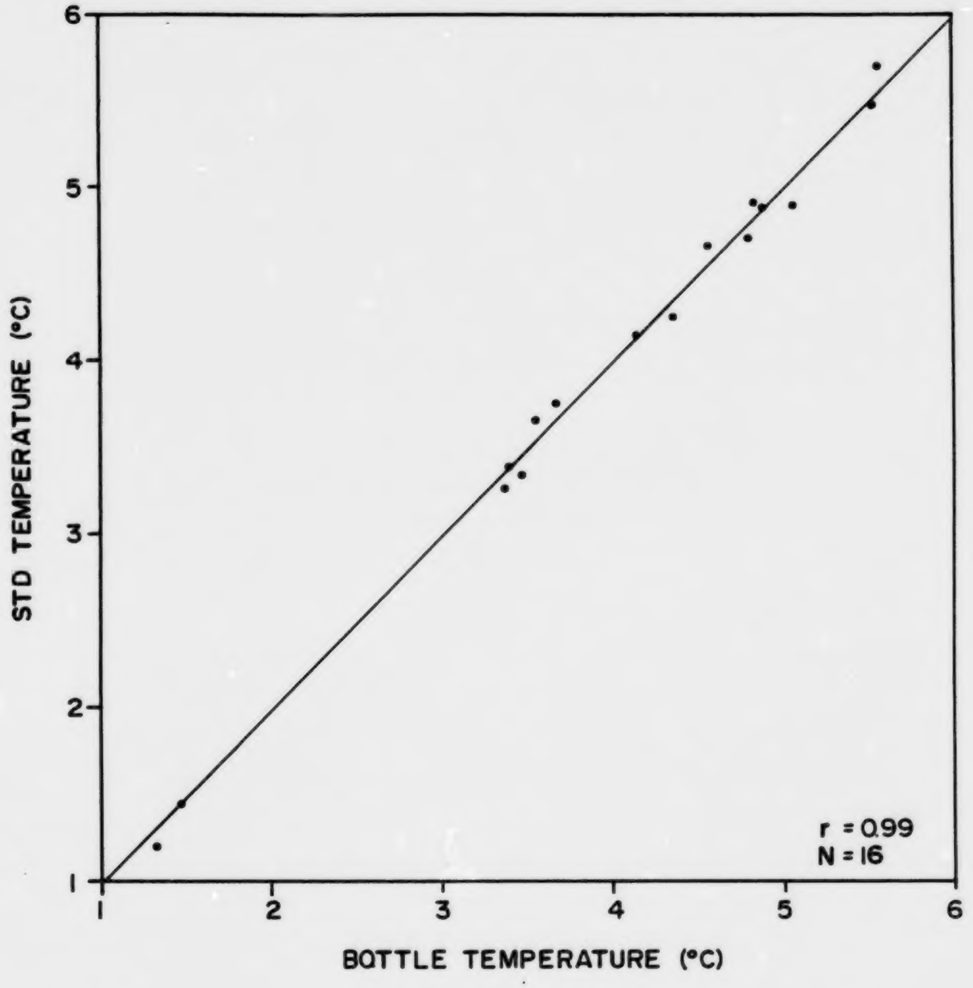

Figure 2. Comparison of temperature measurements obtained using the Applied Microsystems STD-12 instrument vs. reversing thermometers mounted on water sampling bottles.

psu), again reflecting the use of bottle salinities obtained at or near the surface. However, two valid samples were collected at considerable depths, where natural variability is assumed to be reduced. In these two cases, the bottle samples were collected concurrently with the CTD measurements. These two samples, collected at stations 109 and 24 (depth of 101 m), indicate that CTD measurements were too low by 0.08 and 0.22 psu, respectively. Accordingly, a reduction of 0.10 psu was applied to all of the salinity data. Given that only two suitable bottle-derived salinity samples were obtained, the accuracy of the salinity data obtained with the STD-12 may be no better than ± 0.15. It should be noted, however, that the precision of these data is likely better.

From the temperature and salinity data, sigma-t or reduced density was computed as

$$\text{sigma-t} = (\text{density} - 1) \times 10^3$$

using the UNESCO equation of state of seawater (Millero and Poisson 1981), applied at a pressure of one atmosphere.

The accuracy of the transmissiometer data is stated to be ± 0.5% according to the manufacturer. No independent measurements of transmissivity or turbidity were obtained from the M.V. Arctic Ivik, although secchi depths were measured at some CTD stations (Appendix 1). The transmissivity measurements were converted to attenuance values (c) in m^{-1}, according to the equation

$$\text{Transmissivity} = \frac{I(r)}{I(0)} = e^{-cr}$$

where I(r) is the light intensity at a distance r from the source and I(0) is the source intensity of the light beam. Attenuance was then computed as

$$c = \frac{-1}{r} \ln \frac{I(r)}{I(0)}$$

where r = 0.25 is the optical beam length.

In a previous study of suspended sediment distributions in the Canadian Beaufort Sea (Hill and Nadeau 1987), an empirical relationship between turbidity and attenuance was derived. While direct measurements of turbidity were not obtained in this study, the computed attenuance levels exhibited an approximate correspondence to the directly measured secchi depths (Fig. 3A).

All CTD-derived data were scanned for obvious errors or inconsistencies. Only a few errors, less than 0.1% of the total data, were identified and corrected. The most common types of errors were

- Large gradients in temperature, salinity and attenuance in the upper 1 m of the water column obtained in the down-cast but not the up-cast. These suspect data were removed from the data record.
- Occasional large deviations in the high gradient zone beneath the upper layer. These suspect values were most evident in the salinity and attenuance values as one- or two-point 'spikes', and were replaced by linear interpolation.

The edited CTD-transmissiometer data are presented in Appendix 2, as vertical profile plots for each measurement site.

Surface Temperature/Salinity Data.--Measurements of temperature and salinity were obtained from the vessel using a Hydrolabs model TC-2 sensor mounted on a submerged mast attached to the vessel. The instrument is accurate to 0.2 C° temperature and 2.0 mmho/cm (0-100K scale) conductivity. The temperature data were recorded continuously onto an analog chart recorder, while conductivity readings were noted manually at time intervals ranging from 15 min to 3 h.

Satellite Data

General Description of Satellite Data Types and Sources.--More extensive synoptic views of the overall distribution of surface water temperature and turbidity were obtained using data collected with the Advanced Very High Resolution Radiometer (AVHRR) on the polar-orbiting NOAA series of satellites. Only NOAA-9 data were used, as described below. These images are obtained in digital computer-compatible tape (CCT) form in each of five separate bands

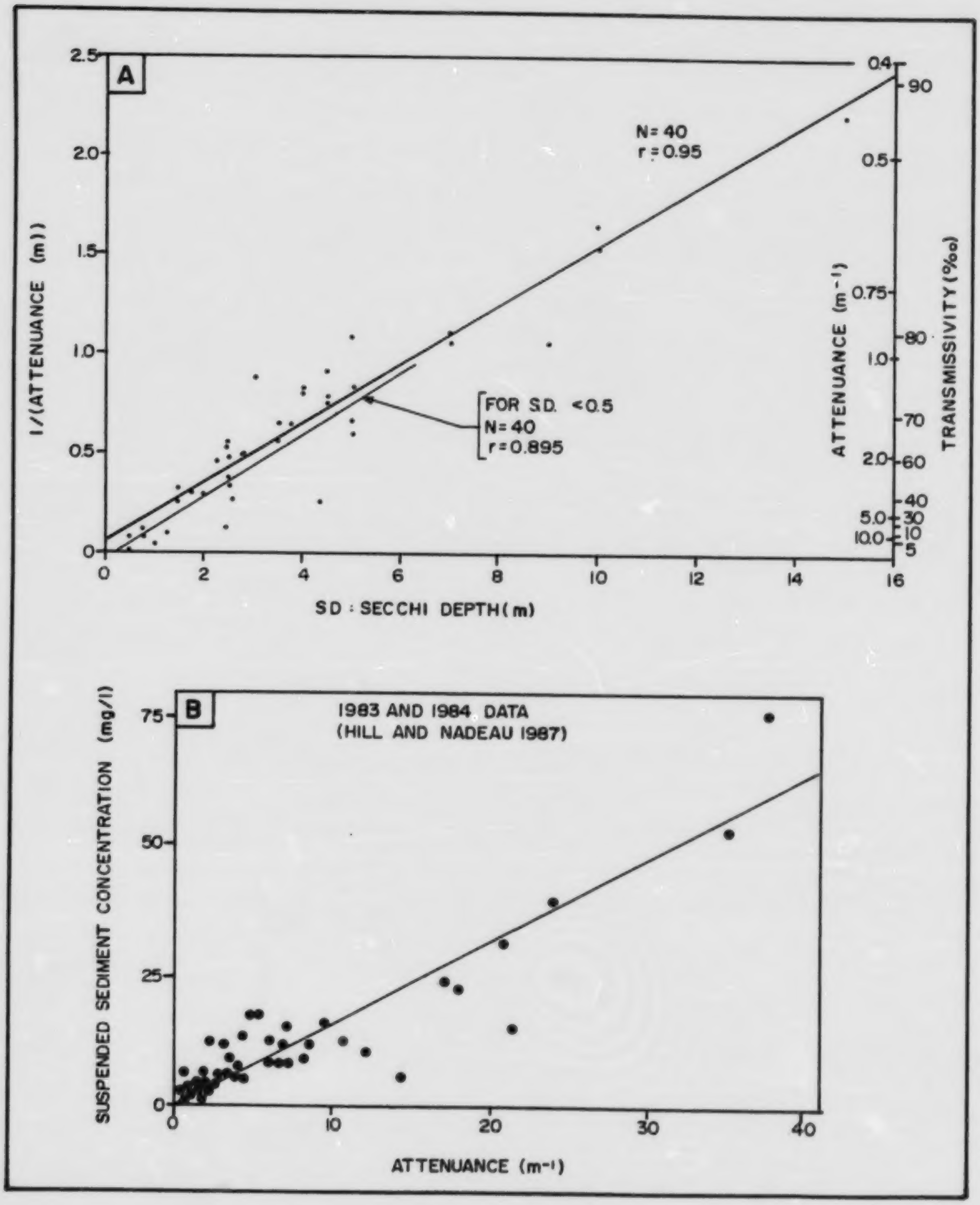

Figure 3. Calibration of turbidity measurements. (A) Reciprocal of attenuance vs. measured secchi depth at CTD-transmissiometer sites. (B) Suspended sediment concentration vs. attenuance derived from inshore data obtained by Hill and Nadeau (1987) in the summers of 1983 and 1984.

within the overall wavelength range 580 nm to 12,500 nm. As transmitted by the satellite, images consist of arrays of 10-bit numbers representing the instrument's response to radiation. Each value represents the radiation from a pixel or picture element. A pixel is the minimum-resolvable portion of the earth's surface, and for a NOAA satellite is approximately 1.2 km^2 in area. Each image consists of successive scanning lines, consisting of 2048 pixels, perpendicular to the projection of the satellite orbit onto the earth's surface. One image is formed for each band of wavelengths sensed by the satellite.

Ideally, the two NOAA satellites normally in operation allow the observation of events on time scales as short as a few hours. Each satellite passes over the study area at least 2-3 times per day during daylight hours, and each pass covers a wide swath (2500 km). In cloudy areas such as the Beaufort Sea, usable imagery is not obtained nearly this often, and only one image per day is routinely archived. However, the availability of numerous daily overpasses greatly increases the likelihood of obtaining data from any particular portion of the area of interest during occasional periods of clear viewing.

In the present study, we used images obtained in bands 1 and 4, which correspond to visible wavelengths (580 nm to 680 nm) and 'thermal' infrared wavelengths (10,500 nm to 11,300 nm), respectively. Band 1 radiance levels (energy per unit time per unit area) are primarily associated with scattering of solar radiation from the uppermost portion of the ocean. Because band 1 reflectance is approximately proportional to the concentration of light-scattering particulates in the upper portion of the water column, band 1 AVHRR images can be used to estimate surface turbidity levels.

Radiances in band 4 are almost entirely attributable to energy radiated by the sea surface, as opposed to scattering of solar energy. As a result, the radiance in this band is closely related to the surface temperature through the radiation laws, as implied by the 'thermal' infrared designation.

Digital images either used or considered for use in this study were obtained from the Remote Sensing Centre of the University of British Columbia (UBC), Vancouver, British Columbia. For 1986, five pairs of NOAA-9 satellite imagery (Table 2) were used in the data analysis, although only four are presented completely in the report. The earliest image, for 26 August 1986, was obtained immediately following the passage of a major storm characterized by strong northwest winds; most of the study area was obscured by cloud. Clouds persisted until 6 September when data were obtained throughout virtually all of the study area. Good viewing conditions persisted on 8 September. Throughout the first ten days of September 1986, winds were weak and variable, and blew predominantly from the east.

Table 2. Satellite data used in this study. The data were obtained from the Remote Sensing Centre of the University of British Columbia (UBC).

Satellite	Orbit	Date	Time (GMT)	Source
NOAA-9	8781	26 Aug 1986	22:07	UBC
NOAA-9	8894	3 Sept 1986	22:35	UBC
NOAA-9	8922	5 Sept 1986	22:13	UBC
NOAA-9	8936	6 Sept 1986	22:03	UBC
NOAA-9	8964	8 Sept 1986	21:14	UBC

Methodology for Satellite Analysis.--The digital tape images were processed using the facilities of the Image Processing Laboratory at the Institute of Ocean Sciences, Sidney, B.C., in a manner similar to that described in previous studies of bowhead whale habitats (Borstad 1985; Thomson et al. 1986; Fissel et al. 1987). The Image Processing Laboratory facilities allow the production of computer graphic representations of the matrix of radiance values associated with individual surface pixels in each distinct wavelength band. The correct position of each pixel was established on an equirectangular projection using image rectification programs and recognizable coastal landmarks. The absolute geometric accuracy is estimated as approximately 2 km.

Our image processing procedure involved the combined use of the band 1 and band 4 images to identify pixels whose high radiance values in both wavelength bands indicated obstruction by cloud and/or ice. (Note: high radiance values in bands 1 and 4 correspond to high values of turbidity and to cold temperatures, respectively. In contrast, dark or low radiance levels on these band 1 and 4 images are associated with clear and warm water, respectively.) Pixels containing ice or cloud were depicted in white on the resulting color images. Land areas were depicted in black and a latitude-longitude grid was superimposed. Pixel radiances in open-water cloud-free areas were represented as six color-coded categories. As in earlier studies (Thomson et al. 1986), the magnitude and range of variation of the band 1 radiance in the studied areas were only about 15% of the corresponding band 4 quantities. As a result, surface spatial details were most clearly extracted from the thermal infrared data.

To display the satellite results we prepared two maps covering the western (140° to 134.5°W) and eastern (136° to 130.5°W) portions of the study area.

Calibration of the Satellite Imagery.--In 1986, calibration of the satellite imagery was facilitated by the extensive set of ship-based oceanographic measurements obtained from 26 August to 8 September in this study. Further boat-based oceanographic measurements were available from the bowhead food availability study being conducted concurrently in the eastern Alaskan Beaufort Sea (4-19 September 1986; Fissel et al. 1987). These two sets of data were used to calibrate the satellite imagery.

Direct measurements of temperature and turbidity (as indicated by attenuance depth values; see Fig. 3B) were obtained within several hours of the times of the 3, 5, 6 and 8 September 1986 imagery. Through comparisons of the ship- and satellite- based data (Figs. 4 and 5), calibration formulae were derived for the satellite measurements of temperature (band 4) and turbidity (band 1).

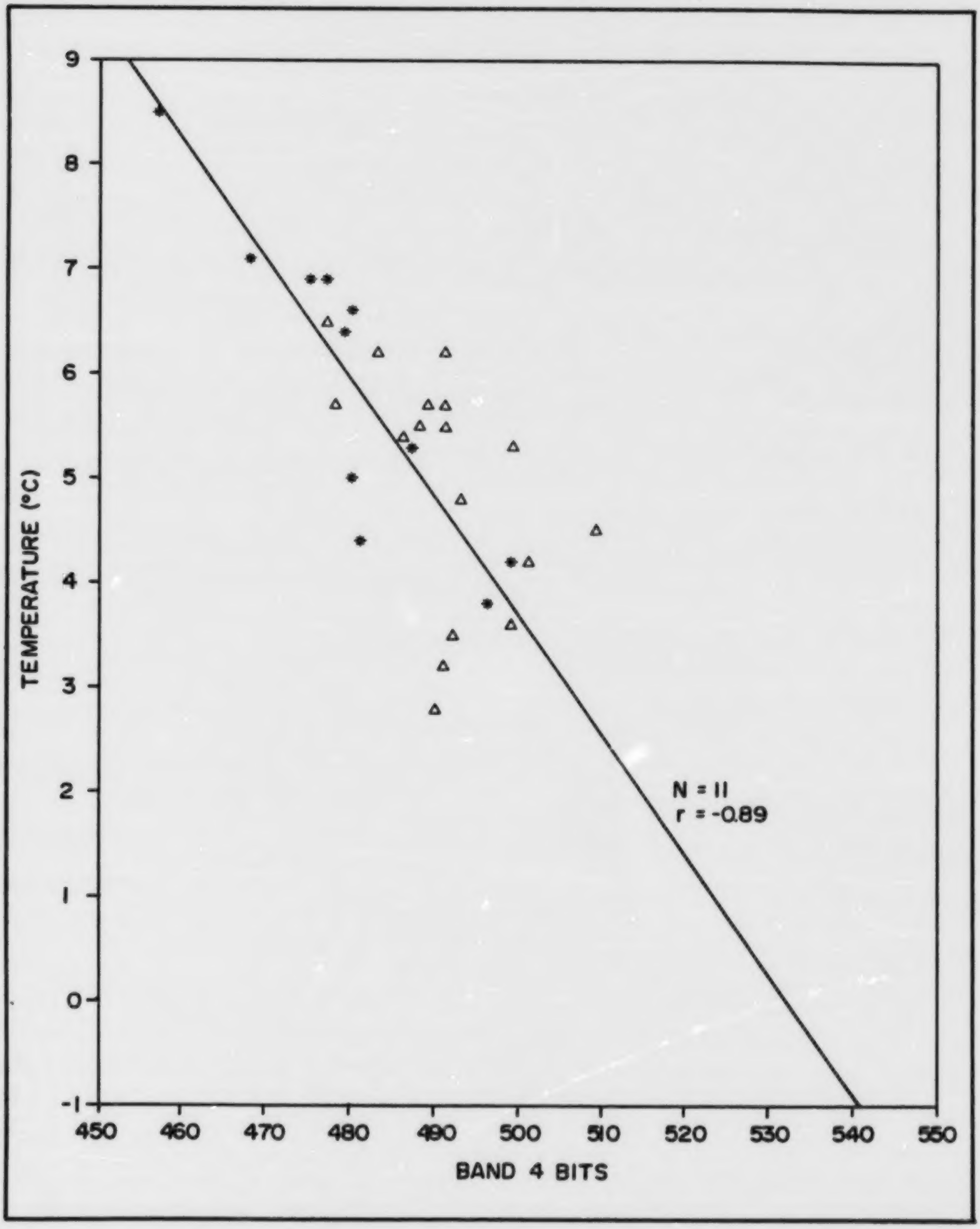

Figure 4. Measured temperature (°C) vs. band 4 satellite measurements. The * symbol denotes measurements obtained <6 h apart; triangles represent time differences >6 h. The linear regression is derived from the former data.

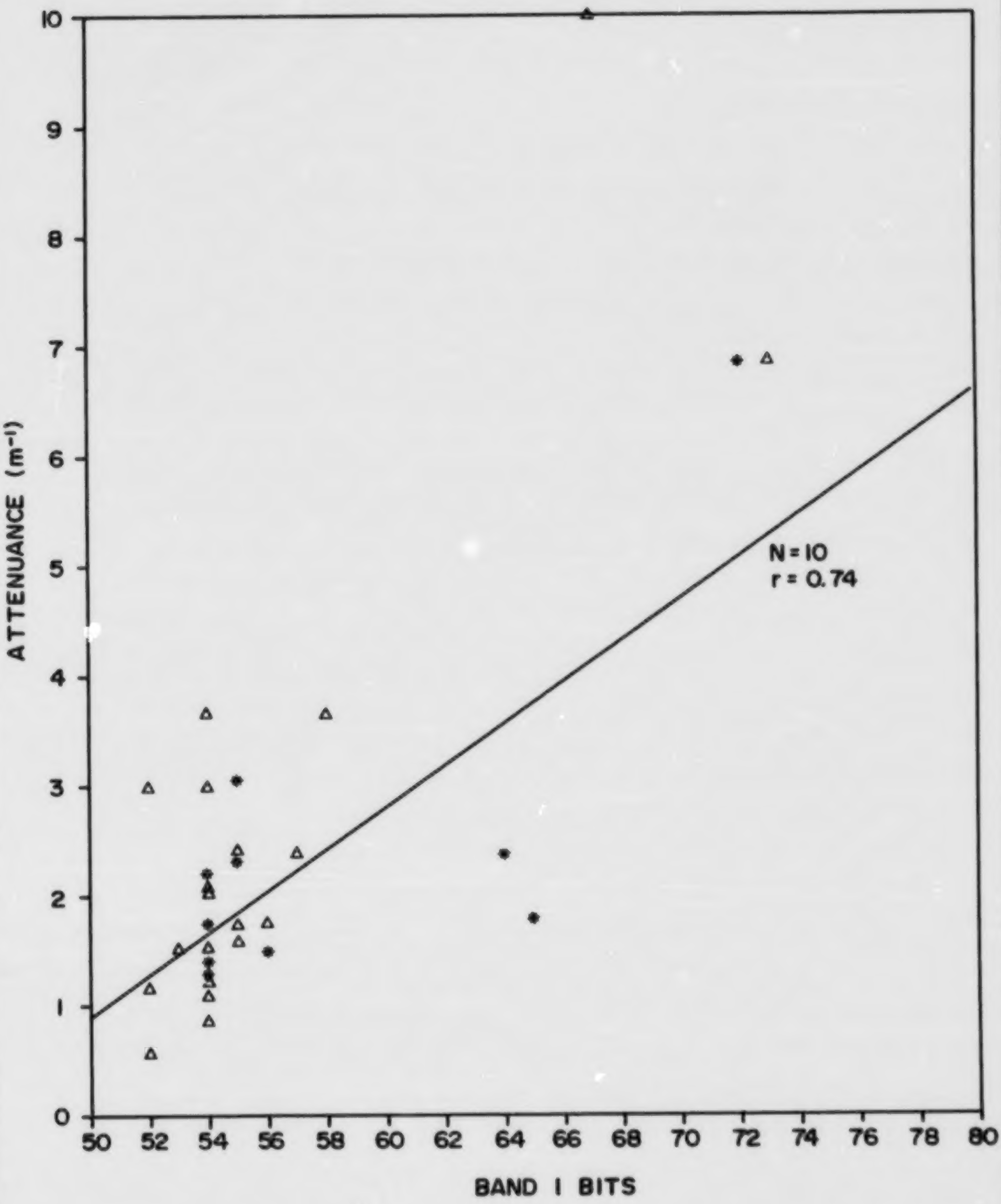

Figure 5. Measured attenuance (m^{-1}) vs. band 1 satellite measurements. The presentation is as for Figure 4.

In the case of temperature, a linear dependence of pixel level on sea-surface temperature was assumed. Only oceanographic data obtained within 6 h of the satellite pass were used in computing the regression line (Fig. 4). The accuracy of the temperature measurements derived from satellite data is estimated to be ± 1.0 C°.

Band 1 satellite data were compared with ship-based attenuance measurements (Fig. 5) and a linear calibration curve was derived by regression. The band 1 satellite data offer limited sensitivity in detecting changes in turbidity for areas outside the intense river plume. The accuracy of the band 1 (visible) satellite data is estimated to be approximately ± 1 m^{-1}.

Net Sampling of Zooplankton

Field Methods for Zooplankton Sampling

Net sampling was conducted at 40 stations along eight transects and at three additional stations near a front (see Figure 6 for station locations and Appendix 4 for sampling details). Two hundred and two plankton samples were collected. Physical data (CTD profiles) were collected at each zooplankton sampling station, although zooplankton could not be sampled at all CTD stations.

Oblique Bongo Tows.--Oblique tows ($n = 46$) were performed using a bongo frame (Posgay and Marak 1980) fitted with two nets 61 cm in diameter. Mesh size was 0.5 mm. Nets were towed at 1.0 m/s. In waters over 50 m deep, oblique tows were made through the upper 50 m of the water column. In waters less than 50 m deep, tows were made to within 2 to 4 m of the bottom. The nets were open during both descent and ascent; in shallow water tows were in a sawtooth pattern so that all tows continued for roughly equivalent periods of time.

Horizontal Bongo Tows.--Two types of horizontal tows were made with the bongo frame assembly. At all stations, nets were towed just below the surface (estimated depth of 1 m) for about 10 min at a speed of 1.2 m/s ($n = 52$

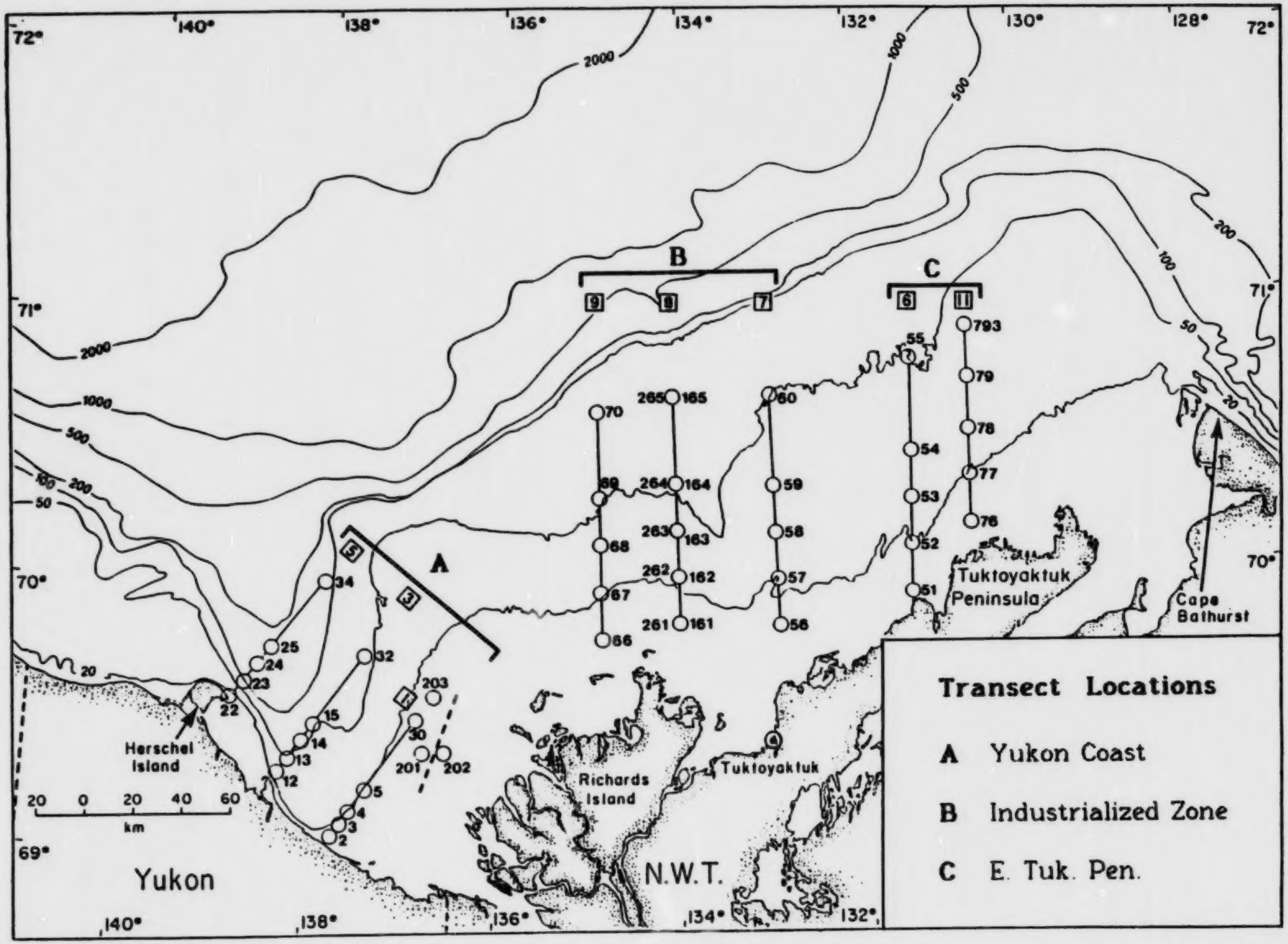
Transect Locations
A Yukon Coast
B Industrialized Zone
C E. Tuk. Pen.
72°
140°
138°
136°
134°
132°
130°
128°
71°
70°
69°
2000
1000
500
200
100
50
20
A
B
C
Herschel Island
Richards Island
Tuktoyaktuk
Tuktoyaktuk Peninsula
Cape Bathurst
Yukon
N.W.T.
20 0 20 40 60
km
2
3
4
5
12
13
14
15
22
23
24
25
30
32
34
201
202
203
66
67
68
69
70
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Figure 6. Locations of transects and stations sampled for zooplankton in late August and early September 1986.

samples). An additional 104 horizontal tows were made at varying depths down to 40 m. An upward looking depth-sounder transducer (Apelco Ranger model 1650) was attached to the bongo frame assembly. It was hard-wired to a surface unit that provided both a hard-copy printout and a digital readout of sampling depth. The bongo frame was lowered to the desired depth and towed for about 10 min before retrieval. Nets were towed at 1.2 m/s. Nets sampled both on the descent to, and the ascent from, desired sampling depths. At the surface, nets sampled the nominal depth for 100% of the time. At the deepest depth sampled with a horizontal tow (40 m), the net sampled the nominal depth for about 75% of the sampling time.

Calorimetry and Lipid Sampling.--To determine the caloric and lipid content of various species and size classes of several groups of zooplankters, the samples from one of the two nets on the bongo assembly were sorted to species onboard ship and frozen. Copepods were sorted to species and lifestage. Each species/lifestage was frozen in a separate vial. Samples for lipid and caloric analysis were placed in separate vials. Samples were sent to Dr. A. Place, Department of Biology, University of Pennsylvania, Philadelphia, for analysis of caloric and lipid content.

Laboratory Analysis of Zooplankton

Zooplankton.--All samples collected for species determinations were preserved in 5-10% buffered formalin in the field and shipped to the laboratory for analysis. Samples were sieved through a 0.25 mm mesh nylon screen, washed with water, and examined under a low-power microscope. Individual animals in all 46 oblique tows and in 51 of 156 horizontal and surface tows were identified to species. Animals in all other samples were identified to major taxonomic group (euphausiid, copepod, etc.). Animals were wet-weighed by taxon to the nearest mg using a Mettler PT 200 electronic balance. If large numbers of organisms were present, which was usually the case, rare and large items were first removed from the sample and processed, and then the remainder of the sample was subsampled with a Folsom Plankton Splitter (McEwen et al. 1954). Items in the subsample were then processed and subsample data were applied to the whole sample to estimate total numbers and

Calorimetric Determinations.--Each species or lifestage subsample was blended and dried to a constant dry weight at 70°C (about 18 h). Samples were then processed in a Parr high pressure oxygen bomb calorimeter.

Lipid Fraction Determinations.--Lipids were extracted from a separate set of frozen samples following the methods of Bligh and Dyer (1959). An aliquot of extract was then dried to a constant mass at 40-50°C. From this information the percentage of sample dry weight consisting of lipid was calculated.

The remainder of the extract was dried under nitrogen. Measured amounts of the dried lipid (200-500 mg) were then loaded onto silica acid columns. Each column was eluted under nitrogen with successively more polar solvents (Nevenzel et al. 1965). These various solvents dissolved different classes of lipids. Each of four lipid classes present in the samples (wax esters, triglycerols, fatty acids and complex lipids) were collected separately, again dried under a stream of nitrogen, re-dissolved in chloroform:methanol (2:1 by volume), and filtered through glass-fibre filters. Solvents were evaporated under nitrogen before final weighing and determination of the total amount of lipid in each class. Phospholipid content in each sample was determined in a separate analysis following the methods of Petitou et al. (1978). The quantity of each of the five classes of lipid thus extracted was expressed as a percentage of the amount of lipid loaded on the column.

Hydroacoustic Surveys of Zooplankton

Hydroacoustic System

An echosounder was used in an attempt to measure the relative biomass of zooplankton at each depth at all locations along transects between stations. The echosounder was also operational during collection of zooplankton samples. The latter data were to allow calibration of the echosounder results.

Echosounder surveys were conducted using a Ross Laboratories 200 kHz echosounder fitted with a custom-designed digitization and data logging system built around an IBM PCXT-compatible microcomputer. Figure 7 is a block diagram showing the components of the system.

The echosounder itself was a standard Ross 200 kHz transceiver and Fineline recorder. It is the same unit as was used by Bradstreet and Fissel (1986). The transducer had a nominal 3.5 degree beamwidth and was driven with 750 watts input power. The sounder was operated on the short pulse setting (605 microsecond pulse length). Pings were emitted every 268 msec (3.73 Hz repetition rate). Timing for the sounder is normally controlled by the mechanical pen drive in the facsimile recorder; a trigger signal to the transceiver is generated each time the pen passes a particular point. This timing system was left in place and used to control the digitization system as well. The difficulty involved in controlling the pen motion with an external trigger necessitated that approach. The sounder was also equipped with a time-varying gain (TVG) to compensate for the rapid variation with depth in the strength of echoes at ranges near the transducer. The TVG is applied as an initial attenuation of 40 dB, which is then decreased to compensate for the inverse fourth power variation with range in the strength of echoes from a discrete target. After the TVG stage, the signals then pass into an envelope detector, whose output is supplied to the facsimile recorder.

The addition of the digital data logging system did not alter the normal operation of the sounder as described above. A signal conditioning circuit was added to the transceiver to amplify the output of the envelope detector to a range suitable for the digitizing card. A second circuit was also installed to condition the trigger pulse supplied by the recorder to a form suitable for use by the data logging system.

The data logging system consisted of an IBM PCXT-compatible microcomputer equipped with a Burr-Brown PCI-2000 digitizing card. The PCI 2000 is equipped with software modules which make its interfacing to an IBM PC-type machine relatively straightforward. The computer was also equipped with a real-time clock card which was used to supply date and time information for the date file headers. The data files were recorded on diskettes.

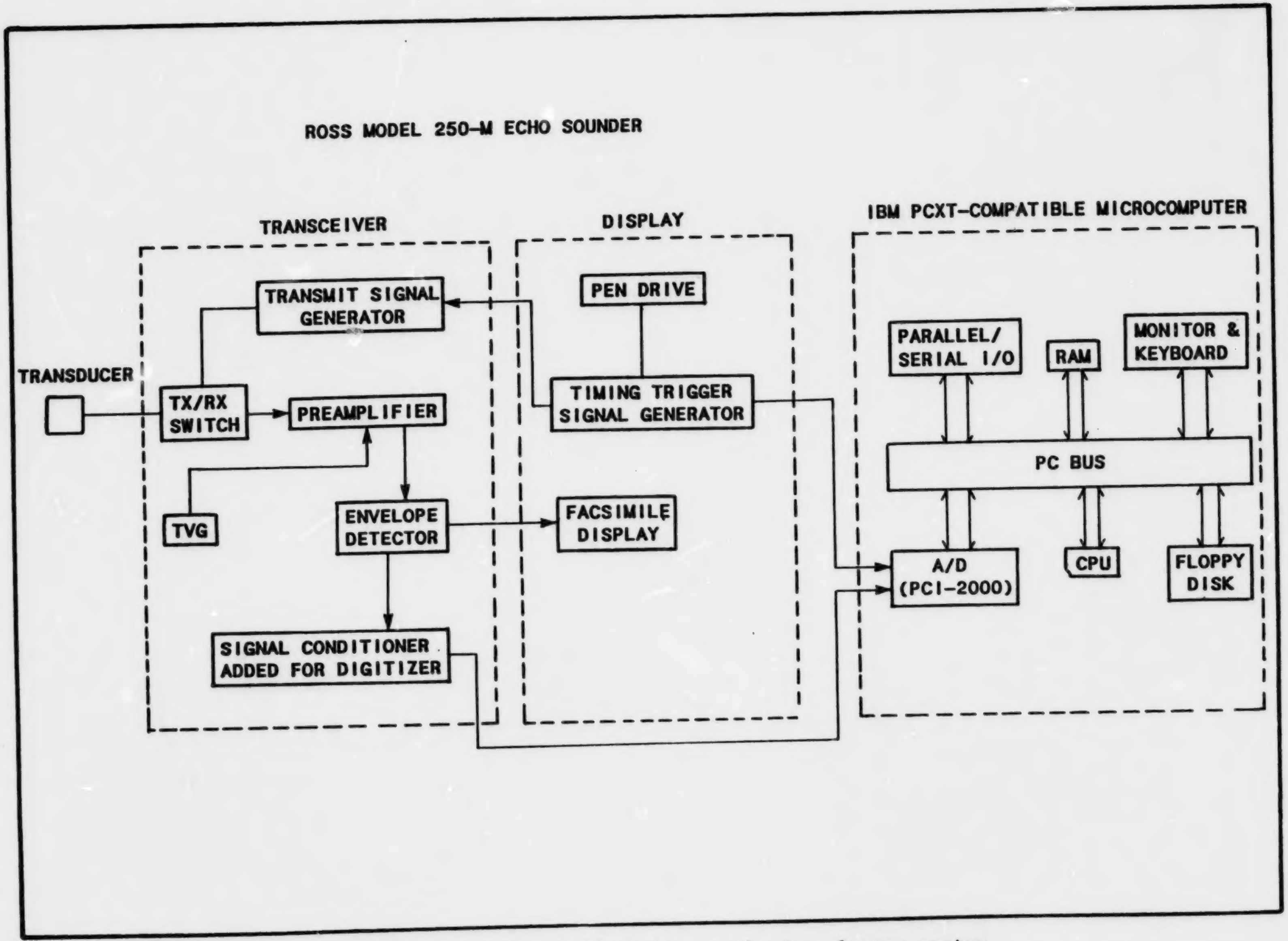

ROSS MODEL 250-M ECHO SOUNDER
TRANSCEIVER
DISPLAY
IBM PCXT-COMPATIBLE MICROCOMPUTER
TRANSDUCER
TX/RX SWITCH
TRANSMIT SIGNAL GENERATOR
PREAMPLIFIER
TVG
ENVELOPE DETECTOR
SIGNAL CONDITIONER ADDED FOR DIGITIZER
PEN DRIVE
TIMING TRIGGER SIGNAL GENERATOR
FACSIMILE DISPLAY
PARALLEL/ SERIAL I/O
RAM
MONITOR & KEYBOARD
PC BUS
A/D (PCI-2000)
CPU
FLOPPY DISK

Figure 7. Block diagram of major components of the hydrocoustic data logger system.

The required vertical resolution in the profiles was 1 m. Allowing for travel time in both directions, it was therefore necessary to collect one sample every 1.33 msec (given a nominal sound speed of 1500 m/sec). The digitization board was triggered by its own clock, which was not synchronized with the trigger signal generated by the echosounder. Simple digitization every 1.33 ms could therefore produce profiles whose depth values were systematically in error by as much as 1 m. As it was not practical, given the project time and budget constraints, to synchronize the trigger signal and the A/D clock, the digitization rate was increased by a factor of 8 in order that the data logging for each outgoing pulse was initiated within 0.167 microseconds of the trigger signal. The systematic depth error was thereby limited to a maximum of 12.5 cm. The digital data stream was subsampled for every eighth point.

Hydroacoustic Data Storage and Processing

Some preliminary data processing was carried out as hydroacoustic profiles were collected in order to reduce storage requirements (all data were to be stored on diskettes), and to allow some interpretation of the data to be carried out in the field. Two general types of hydroacoustic sampling were conducted: surveys and zooplankton tows.

In survey mode, the ship steamed at a steady speed on a fixed course. The sounder was operated continuously as the ship steamed along. Horizontally averaged vertical profiles of the raw sounder echoes were computed and stored to diskette files. The horizontal averaging intervals were specified as distances in metres; the ship's speed was supplied to the program which then used it to convert the specified averaging distance to time and thence to number of pings, n. The n values at each depth were then averaged together, and the mean depth profile of echo strength (and associated variances) was stored to diskette file. Successive average profiles were constructed and stored until the survey run ended. Each run constituted one data file.

In zooplankton tow mode, the echo profile resulting from each ping was stored in memory until the tow was completed. The time at which each echo profile was collected was also stored. After completion of the tow, profiles between any two times specified by the operator (corresponding, for example, to the start and end of the net sampling) were averaged together and stored.

Survey data could be recalled and averaged on various horizontal and vertical scales if desired. No other processing was carried out in the field.

After the field program was completed, the data were processed to calculate distributions of volume backscattering strength. The effect of the depth (d) and time-varying gain was first removed by multiplying each profile by a scaling factor A, where

$$A = \begin{cases} 100 & \text{for } 0 \leq d \leq 1.9 \text{ m} \\ 100\,(1.9/d)^2 & \text{for } 1.9 \text{ m} \leq d \leq 19 \text{ m} \\ 1 & \text{for } d > 19 \text{ m} \end{cases}$$

The scaled data were then subjected to further horizontal or vertical averaging as required to produce distributions that were spatially compatible with the zooplankton and water property data.

Calibration figures for the sounder for beamwidth, transmission power and receiving sensitivity were not available. As a result, only relative figures for volume backscatter could be calculated. Volume backscattering strength SV is defined as

$$SV = EL - SL + 20 \log r + 2ar - 10 \log CtB/2 \qquad (1)$$

where EL is the echo level, SL is the source level (both measured in dB re 1 microPascal), r is the range (in metres) to the target volume, a is the absorption coefficient (dB/m), C is the speed of sound (m/s), t is the pulse length in seconds, and B is the effective solid angle of the beam. Since SL and B were unknown, we calculated a relative volume scattering strength

$$SVR = 20 \log E + 20 \log d + 2 ad \qquad (2)$$

where E is digitized echo level (after spatial averaging) and d is the depth to the centre of the target volume. The value of a was taken to be 0.064 dB/m for 200 kHz sound in seawater at approximately -1°C. Values of SVR were computed for the various data runs for a variety of horizontal and vertical averaging distances.

Data Processing and Analysis

Biological data were entered into an IBM XT computer and analyzed on a Tandon AT computer using programs written for this project, Lotus 123, and the BMDP statistical software package (IBM PC version, Dixon 1985). Physical data were merged with the biological data using the Lotus 123 program.

PHYSICAL CHARACTERIZATION OF THE STUDY AREA

Wind Conditions

Regional wind patterns are particularly important to the physical oceanographic characteristics of the study area, through wind driven advection of differing water masses (Thomson et al. 1986) and through coastal upwelling driven by easterly winds (Borstad 1985). To examine the prevailing wind conditions preceding and during the data collection period, wind data were obtained from five coastal weather stations: Komakuk Beach, Herschel Island, King Point, Shingle Point, and Tuktoyaktuk (see Appendix 3 and Fig. 8).

In the two weeks prior to this study, the regional wind patterns were dominated by two northwesterly wind events. The first (18-19 August) was comparatively small in magnitude and of short duration. The second event of westerly and northwesterly winds (22-24 August) was much stronger, with peak wind speeds ranging from 15 to 25 m/s (28 to 46 knots) among the measurement sites (Fig. 8).

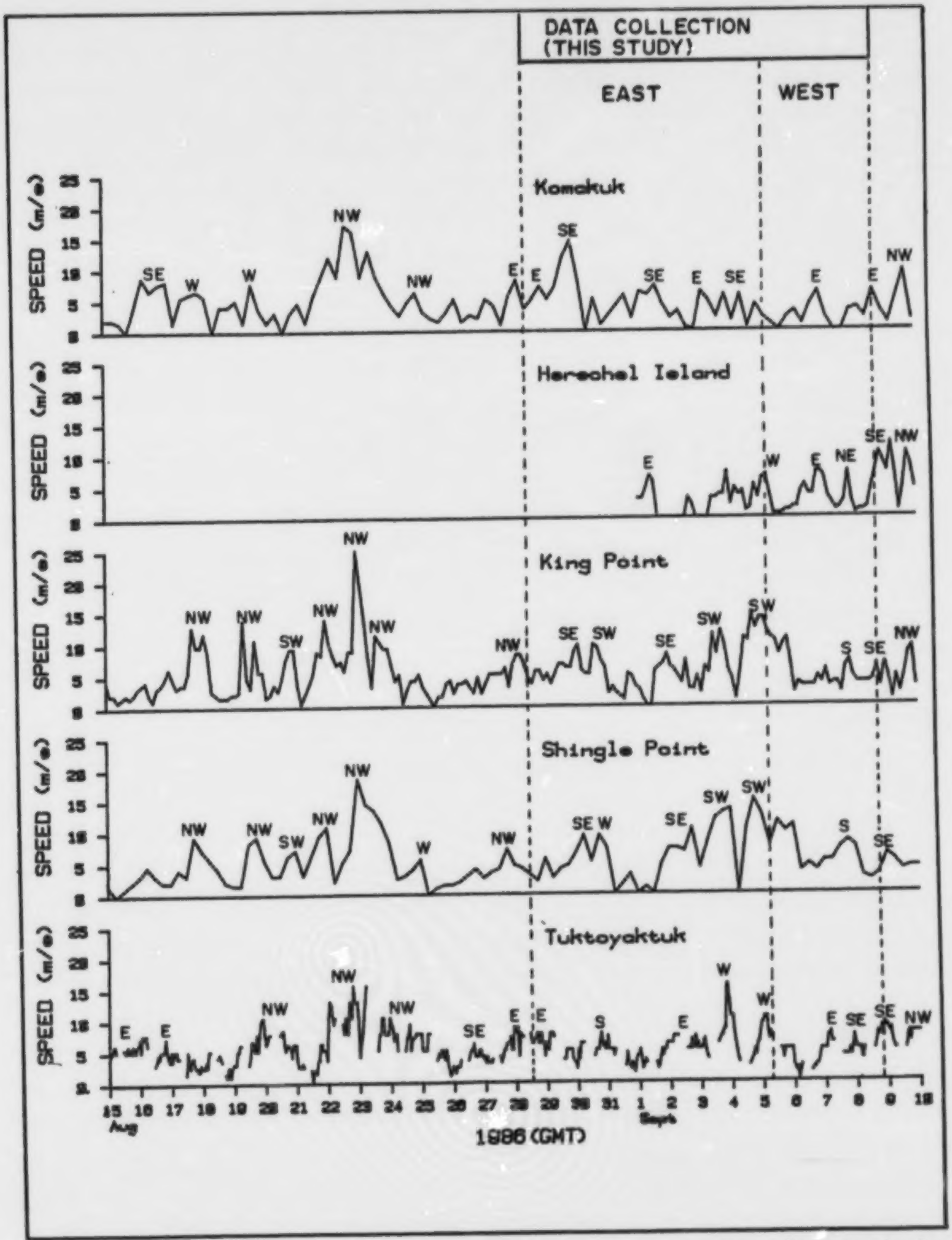


Figure 8. Wind speed measurements at five coastal observation sites bordering the study area. The wind direction is annotated when wind speed exceeded 5 m/s. (N - from the north, W - west, E - east, S - south).

During the field period (28 August to 8 September), regional winds were unusually weak and variable in direction. In the eastern portion of the study area, at Tuktoyaktuk, the winds had maximum speeds of only 8 m/s and were generally blowing from the south through east quadrant. This pattern of weak southerly to easterly winds was interrupted only briefly on 4 September and again on 5 September by short (<12 hour) periods of westerly winds.

In the western portion of the study area, the winds at King Point and Shingle Point were dominated by strong southwesterly winds blowing offshore. Such wind conditions were particularly prominent on 3-6 September. On these occasions, the winds were weak and variable at two measurement sites farther west--Herschel Island and Komakuk Beach. Similar occurrences of intense local southwesterly winds along the Yukon coastline between Kay and Shingle Points have been reported previously (Bradstreet and Fissel 1986) and are well known to pilots operating in the area. They likely result from mountain barrier baroclinicity (orographic effects) associated with downward flow of air over the lee side of the Richardson mountain range. Orographic effects have been observed to extend as much as 50 km offshore from the coastline of eastern Alaska to Mackenzie Bay (Kozo and Robe 1986).

Regional Sea Ice Conditions

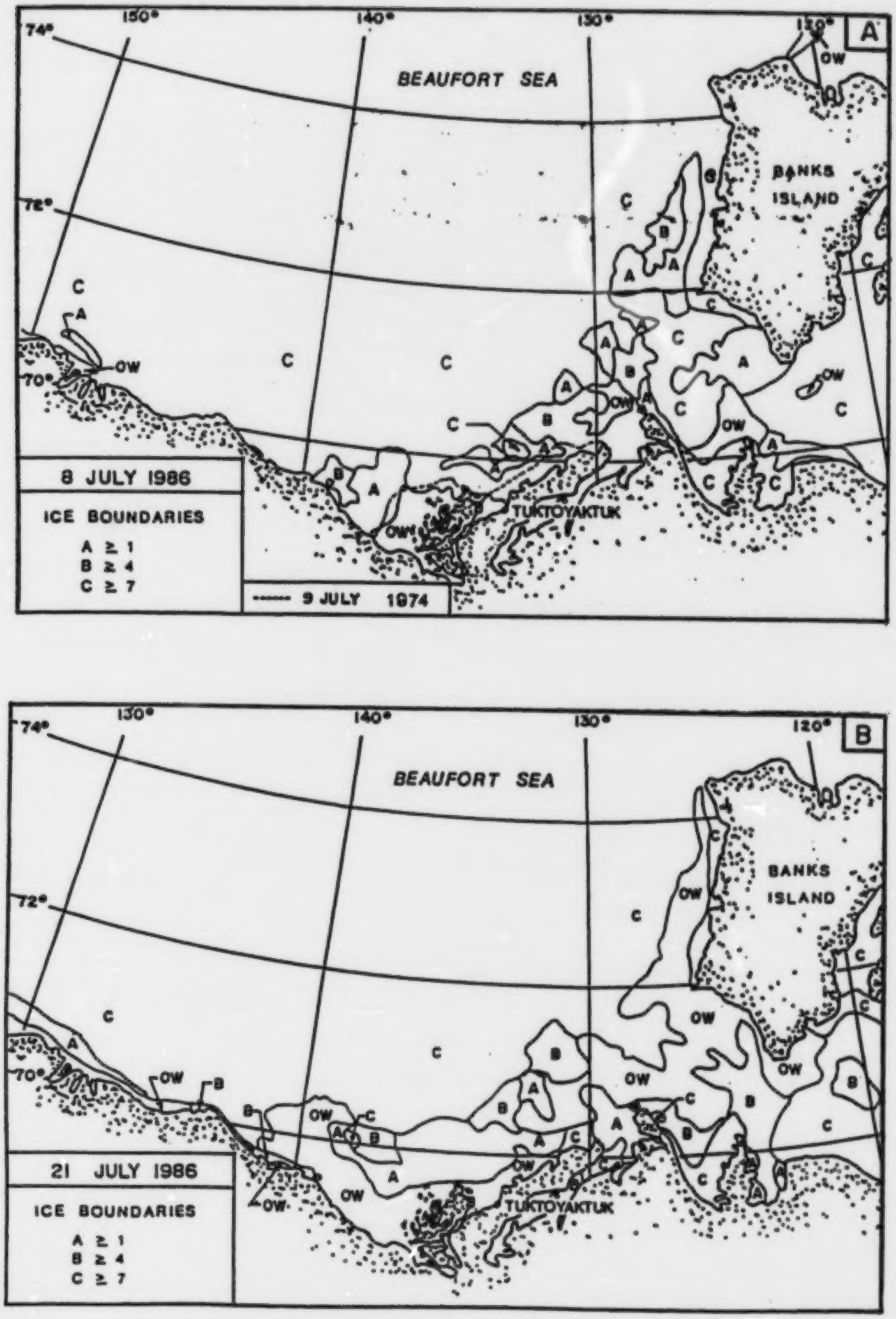
The distribution of sea-ice is a major factor determining regional oceanographic conditions within the study area. Sea-ice distributions are subject to a very large degree of annual variability during the summer months (Brower et al. 1977). The normal pattern of ice clearing commences with breakup of the coastal band of landfast ice in late June and early July. Due to the proximity of the Yukon coastline to the Mackenzie River discharge, the warm river water assists in maintaining open-water conditions through most of Mackenzie Bay after breakup. However, considerable quantities of ice can occur to the west and offshore of Herschel Island at any time during the summer. Occasionally, strong westerly winds advect this ice eastward as extensive bands of sea-ice along the Yukon coastline.

Sea-ice conditions during the summer of 1986 were fairly typical of the conditions experienced over the last 15 years. Sea-ice concentrations were significantly less extensive than those of 1985; when clearing of sea-ice from Richards Island to Amundsen Gulf in July and August was unusually slow (Bradstreet and Fissel 1986).

Local clearing of coastal sea-ice was well underway by early July 1986 (Fig. 9a) in the regions adjoining the Mackenzie River delta and at the entrance to Amundsen Gulf (the so-called Cape Bathurst Polynya; Smith and Rigby 1981). Open water also appeared off the Alaskan coast near the Sagavanirktok, Kuparuk, and Colville River estuaries. By 15 July, a continuous band of open water appeared off Mackenzie and Kugmallit Bays. By 21 July, this clearing extended eastward, through scattered ice floes, to connect with the rapidly expanding open water area off Amundsen Gulf and Banks Island (Fig. 9b).

Melting of sea-ice floes continued throughout August (Fig. 10). By mid-August, most of the broad continental shelf of the Canadian Beaufort Sea was clear of sea-ice. This open water area extended westward to 146°W, with the exception of a band of scattered floes 10 to 50 km off the eastern Alaskan coastline. Scattered ice floes were also present in Franklin Bay and in the easternmost portions of Amundsen Gulf.

By 2 September, the offshore retreat of the pack ice had ceased, with a shoreward advance occurring in some areas, particularly at latitudes between 71 and 72°N (Fig. 11) off Liverpool Bay and Baillie Islands. The shoreward movement of the pack-ice was likely caused by the prevailing northwesterly winds of 18 to 26 August. In mid-September, the open water area expanded again except in the Eastern Alaskan Beaufort Sea, where higher concentrations of sea-ice floes moved into the region from the northwest.



A
74°
150°
140°
130°
120°
72°
70°
BEAUFORT SEA
BANKS ISLAND
TUKTOYAKTUK
A
B
C
OW
8 JULY 1986
ICE BOUNDARIES
A ≥ 1
B ≥ 4
C ≥ 7
9 JULY 1974
B
74°
130°
140°
130°
120°
72°
70°
BEAUFORT SEA
BANKS ISLAND
TUKTOYAKTUK
A
B
C
OW
21 JULY 1986
ICE BOUNDARIES
A ≥ 1
B ≥ 4
C ≥ 7

Figure 9. Charts of regional sea-ice concentrations on (A) 8 July 1986 and (B) 21 July 1986 (data source: Environment Canada).

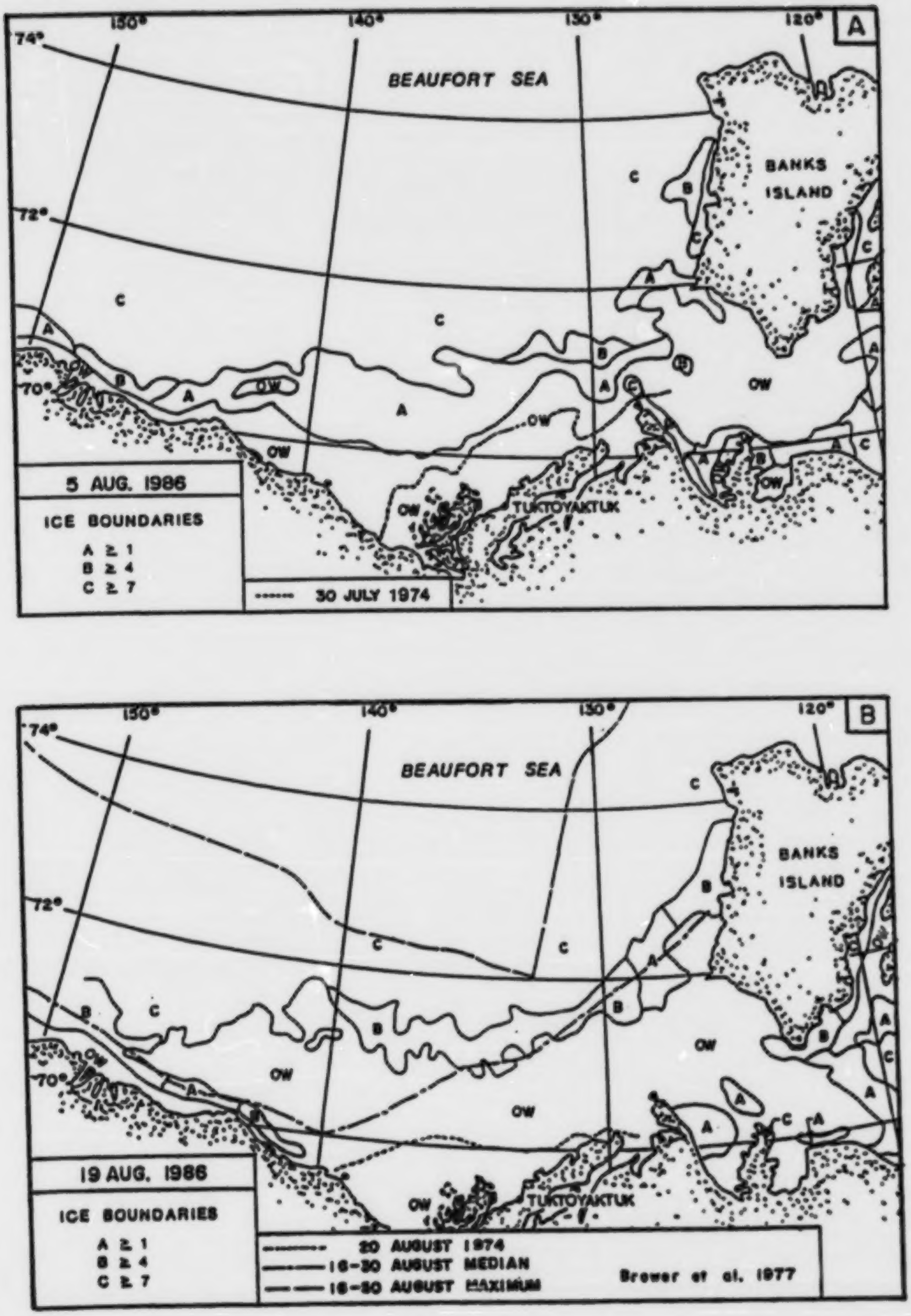

A
150°
140°
130°
120°
74°
72°
70°
BEAUFORT SEA
BANKS ISLAND
TUKTOYAKTUK
OW
A
B
C
5 AUG. 1986
ICE BOUNDARIES
A ≥ 1
B ≥ 4
C ≥ 7
30 JULY 1974
B
19 AUG. 1986
ICE BOUNDARIES
A ≥ 1
B ≥ 4
C ≥ 7
20 AUGUST 1974
16-30 AUGUST MEDIAN
16-30 AUGUST MAXIMUM
Brower et al. 1977

Figure 10. Charts of regional sea-ice concentrations on (A) 5 August 1986 and (B) 19 August 1986 (data source: Environment Canada). Also shown are the locations of the pack-ice edge for median and maximum open-water conditions (Brower et al. 1977) and the pack-ice location in 1974 during severe ice conditions.

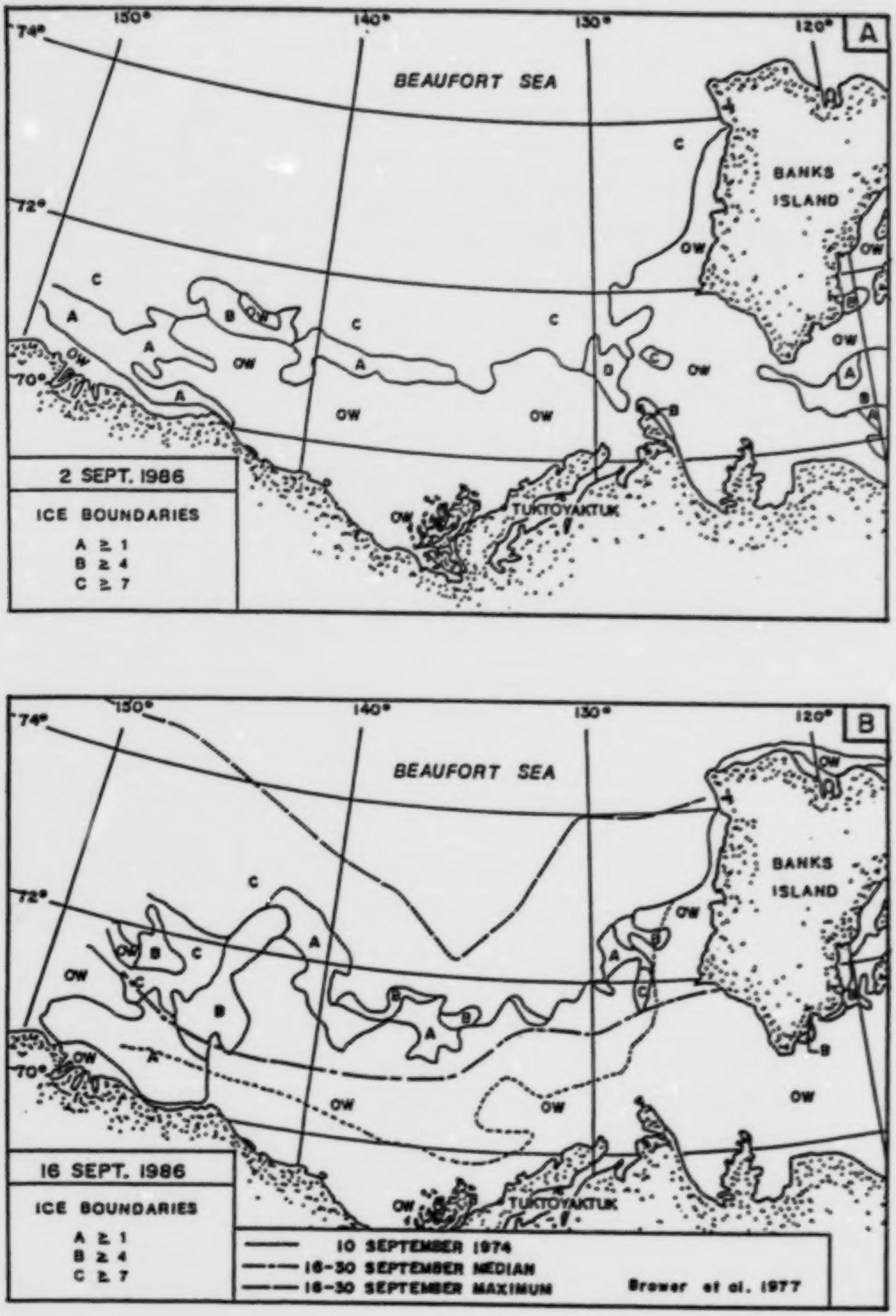

A
74°
150°
140°
130°
120°
72°
70°
BEAUFORT SEA
BANKS ISLAND
TUKTOYAKTUK
OW
A
B
C
2 SEPT. 1986
ICE BOUNDARIES
A ≥ 1
B ≥ 4
C ≥ 7
B
16 SEPT. 1986
10 SEPTEMBER 1974
16-30 SEPTEMBER MEDIAN
16-30 SEPTEMBER MAXIMUM
Brower et al. 1977

Figure 11. Charts of regional sea-ice concentrations on (A) 2 Sept. 1986 and (B) 16 Sept. 1986 (data source: Environment Canada).

Water Mass Analysis

Definition of Water Masses

Temperature-salinity properties provide a useful means of inferring the origin and recent history of the water overlying the Beaufort Sea continental shelf. In summer, T/S properties exhibit large differences according to location and depth, resulting from varying combinations of two very different water mass types.

1. Warm Mackenzie River water (salinity of 0 psu; temperature ranging from 5°C in mid-June up to 16-20°C in late July-early August). The average annual Mackenzie River discharge is the equivalent of a 6.2 m deep freshwater layer covering the Mackenzie shelf (Macdonald et al. 1987).
2. Cold, saline Arctic Surface Water (ASW) which occupies virtually all of the continental shelf through the winter months. Temperatures range from -1.0 to -1.8°C with salinities of 31 to 33 psu.

In addition to direct mixing of Mackenzie River and ASW, other physical mechanisms also can influence local T/S properties. The two most significant physical mechanisms are the following:

3. Melt of the regional sea-ice cover in late spring and early summer, resulting from heat gained through Mackenzie River inputs and solar insolation. The mean thickness of the regional ice cover is 1.8 m, with sea-ice salinity ranging from 0 to 8 psu (Melling and Lewis 1982).
4. Solar insolation and the resulting heating of surface waters over the Beaufort Sea shelf.

Advection of other water types into the region has also been considered in previous studies. In the summer, two water masses of non-local origin may be of some importance:

5. Bering Sea Water which is advected eastward along the outer continental shelf by the Beaufort Undercurrent in the form of a subsurface temperature maximum at salinities of 30.5 to 32.5 psu (Aagaard 1984). Although the Beaufort Undercurrent appears to continue eastward beyond Mackenzie Canyon, prior to 1986 Bering Sea water had not been unambiguously observed (on the basis of T/S

properties) to the east of 143°W (Paquette and Bourke 1974; Fissel et al. 1987). In September 1986, a very prominent subsurface core of Bering Sea Water was observed between 142 and 144°W over the outer continental shelf (Fissel et al. 1987), with a maximum temperature of 4.2°C. However, the warm subsurface maximum did not extend as far east as 141°W in mid-September 1986.

6. Warm water associated with the Bathurst Polynya in the entrance to Amundsen Gulf may also be advected onto the Mackenzie shelf, in the form of a subsurface temperature maximum. Evidence for such a feature was presented by Mountain (1974) and Macdonald et al. (1987). In the latter study involving 1975 observations, warm (>4°C) water was present to the east of 132°W on the 31 psu isohaline, while temperatures were much lower (<1°C) to the west (Fig. 12).

The temperature-salinity plots derived from the 28 August-8 September 1986 CTD data are shown in Figure 13. The dominance of direct mixing of Mackenzie River and Arctic Surface Water is apparent, given the tendency of T/S values to lie within a broad swath connecting Arctic Surface Water characteristics with warm, zero salinity water (temperatures 10 to 18°C). The latter low salinity and high temperature correspond to Mackenzie River discharge.

For the purposes of subsequent analysis in this study, we have chosen to define five water types in an empirical manner. The coldest and most saline water type, referred to as **Arctic water**, includes water whose T/S values are strongly influenced by ASW. This water type is defined to include salinities exceeding 27.5 psu for all temperatures; and temperatures less than 1.5°C for all salinities; and intermediate values below the T/S line connecting (1.5°C, 23 psu) with (3.0°C, 27.5 psu).

The definitions of the remaining water types were chosen through consideration of distributions of surface layer T/S properties. Previous studies (Fissel and Birch 1984; Thomson et al. 1986) demonstrate that the Mackenzie River influence on surface layer water properties occurs in two reasonably distinct forms (Fig. 14):

1. **Intense River Plume Water** - an area of high temperatures and turbidities and low salinities situated immediately adjacent to the Mackenzie River Delta. The offshore boundary of the intense plume is clearly distinguished as an intense horizontal gradient in which

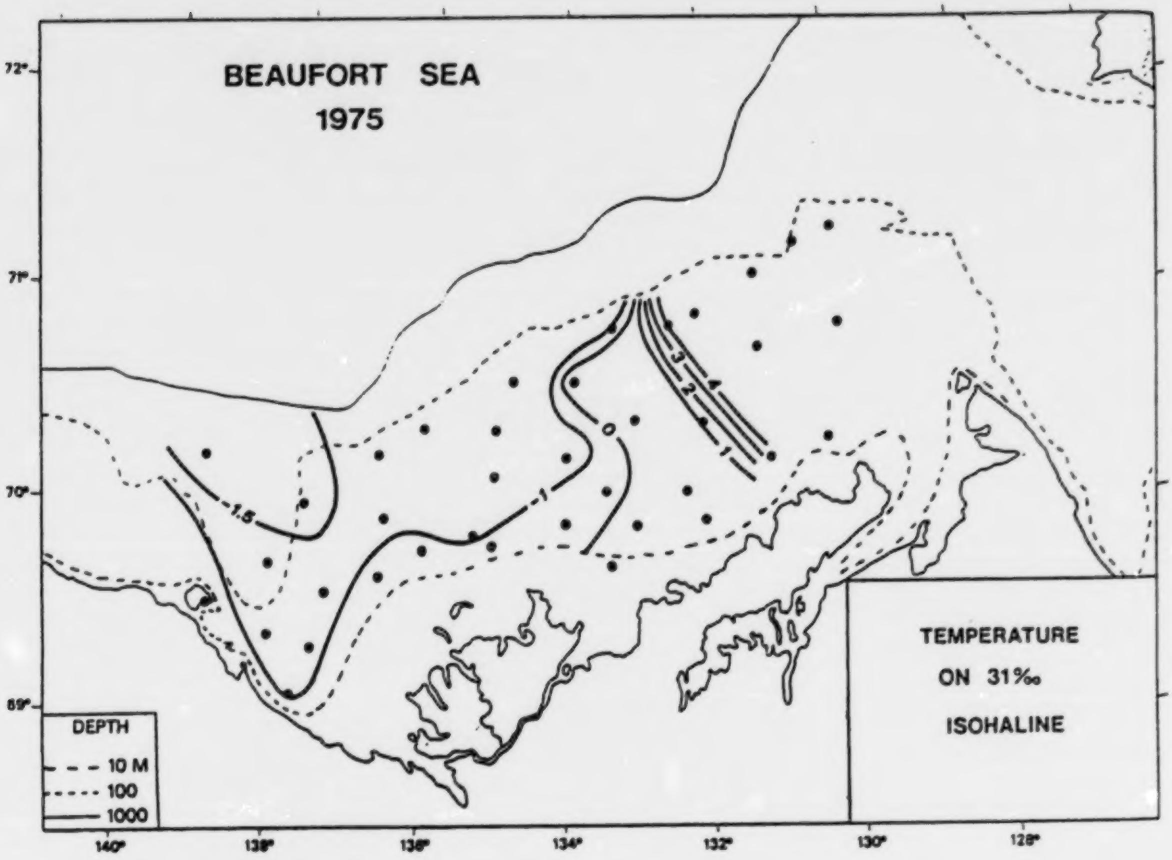

BEAUFORT SEA
1975
TEMPERATURE
ON 31‰
ISOHALINE
DEPTH
10 M
100
1000
72°
71°
70°
69°
140°
138°
136°
134°
132°
130°
128°
1.5
1
0
3
2
1

Figure 12. Map of temperatures on the salinity = 31 psu surface, as observed in the summer of 1975 (from Macdonald et al. 1987).

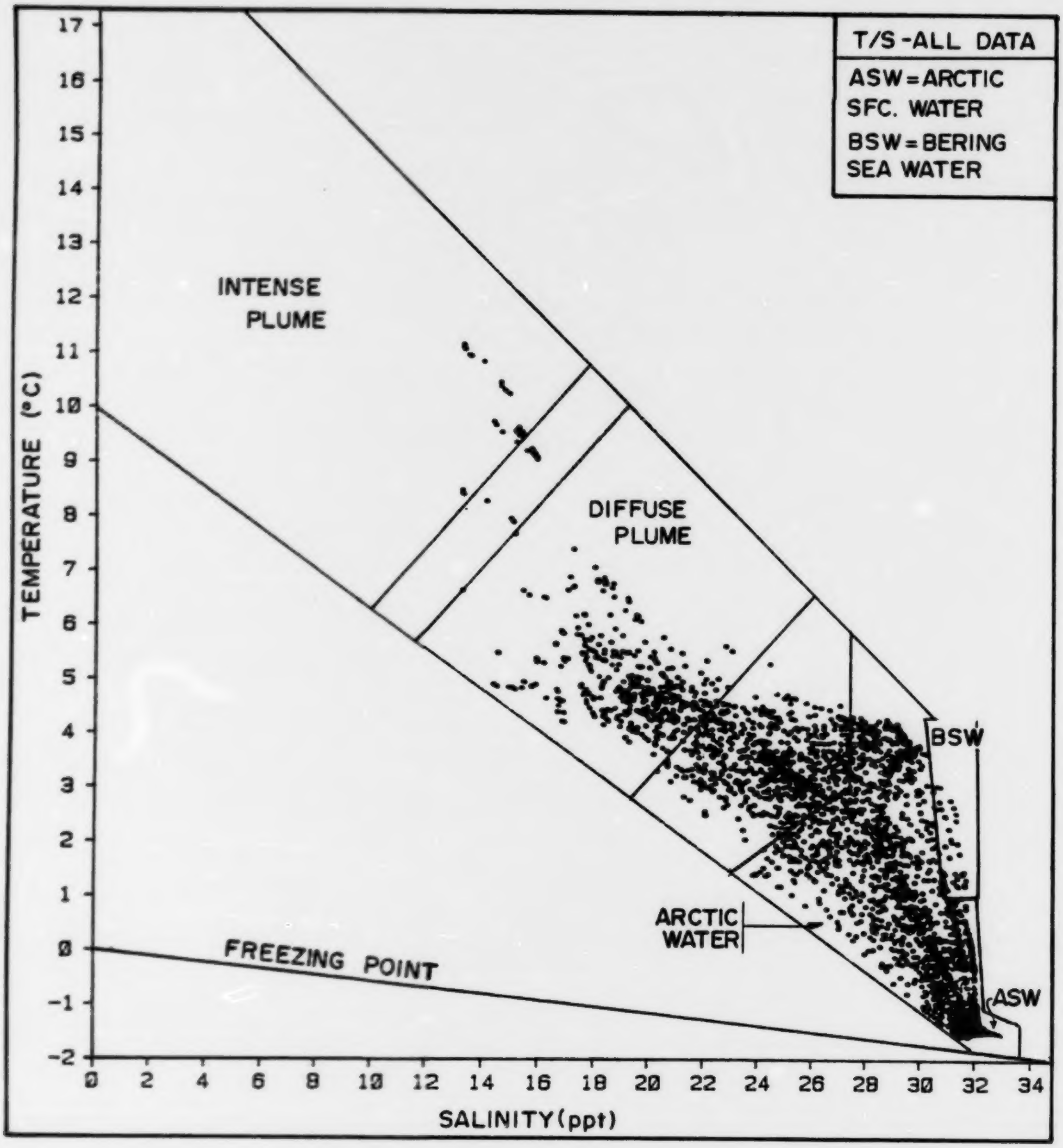


Figure 13. Temperature vs. salinity diagram for all CTD data collected during this study from 28 August to 8 September 1986. The T/S regions for standard water masses, Arctic Surface Water (ASW) and Bering Sea Water (BSW), are shown, along with the T/S curve representing the freezing point of seawater. Also shown are water types (intense plume, diffuse plume and Arctic water) defined for subsequent use in the present study.

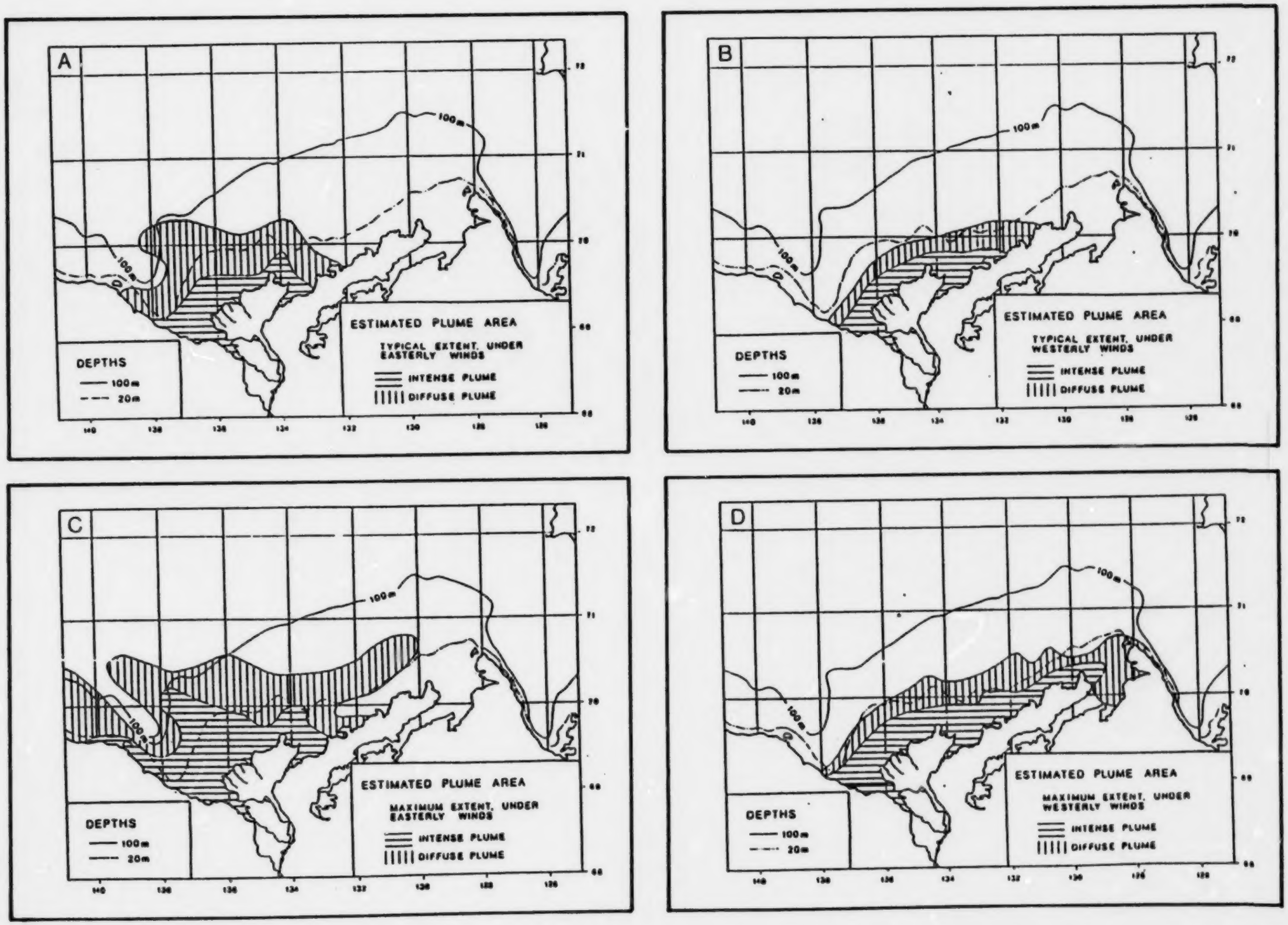

A
100m
ESTIMATED PLUME AREA
TYPICAL EXTENT, UNDER EASTERLY WINDS
INTENSE PLUME
DIFFUSE PLUME
DEPTHS
100m
20m
B
100m
ESTIMATED PLUME AREA
TYPICAL EXTENT, UNDER WESTERLY WINDS
INTENSE PLUME
DIFFUSE PLUME
DEPTHS
100m
20m
C
100m
ESTIMATED PLUME AREA
MAXIMUM EXTENT, UNDER EASTERLY WINDS
INTENSE PLUME
DIFFUSE PLUME
DEPTHS
100m
20m
D
100m
ESTIMATED PLUME AREA
MAXIMUM EXTENT, UNDER WESTERLY WINDS
INTENSE PLUME
DIFFUSE PLUME
DEPTHS
100m
20m

Figure 14. The spatial extent of the Mackenzie River plume, as derived from summer satellite data of 1980-1983, inclusive. Typical plume areas are shown for (A) easterly winds and (B) westerly winds. Maximum plume areas are shown for (C) easterly and (D) westerly winds (from Thomson et al. 1986).

water properties decrease considerably over distances of a few kilometres or less.

2. **Diffuse Plume Water** - an area adjoining the intense plume in which riverine water characteristics are markedly reduced, but remain significantly enhanced over those of the Arctic water. The diffuse plume is heterogeneous in nature, with variations in water properties taking the form of local minima or maxima. Its outer (offshore) boundary is difficult to map unambiguously due to the lower levels of riverine characteristics and the tendency for filaments and meanders, often transitory in nature, to protrude outward.

The water mass characteristics defining the intense and diffuse plumes were chosen through careful examination of surface T/S properties along the boundaries of each region (see "Surface Distributions" section). The offshore limits of the intense plume T/S characteristics were clearly identified as a T/S line joining 8°C, 19 psu with 9°C, 16 psu. The inner boundary of the diffuse plume, corresponding to the offshore side of the large scale fronts bordering the intense plume, was approximated by a 1°C temperature reduction and a 2 psu salinity increase from those at the outer edge of the intense plume.

The outer limits of the diffuse plume were less certain. Over the Mackenzie Shelf, there was no marked gradient separating riverine from Arctic Water. However, the 4°C isotherm and 22 psu isohaline appeared to mark the edge of the portion of diffuse plume extending northwest along the edge of the Mackenzie Canyon. Therefore, this value was used to select a T/S line perpendicular to the mixing lines joining intense plume and Arctic water.

The defining T/S characteristics of the intense plume, diffuse plume, Arctic Water, and the intermediate categories (intense-diffuse and diffuse-Arctic) are displayed in Figure 13, superimposed on a T/S diagram of all measurements.

Geographical Differences in T/S Characteristics

The temperature-salinity characteristics varied significantly across the study area (see Figs. 15 and 16). Aside from the self-evident presence or absence of the intense and diffuse plume water, systematic differences

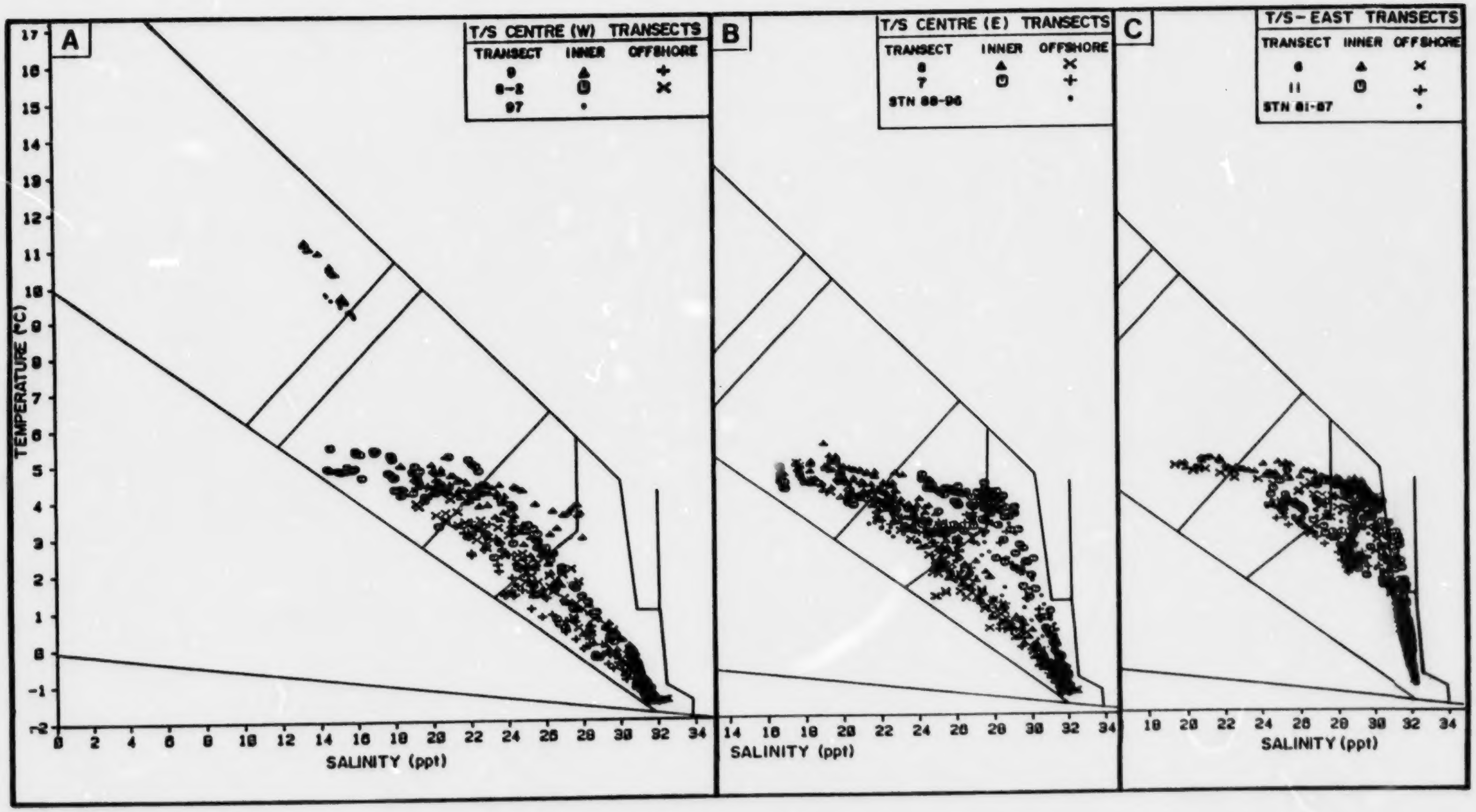


Figure 15. Temperature vs. salinity diagrams of CTD data obtained on (A) centre-west transects 8-2 and 9; (B) centre-east transects 7 and 8; and (C) eastern transects 6 and 11. The water mass boundaries are identical to those labeled on Figure 13.

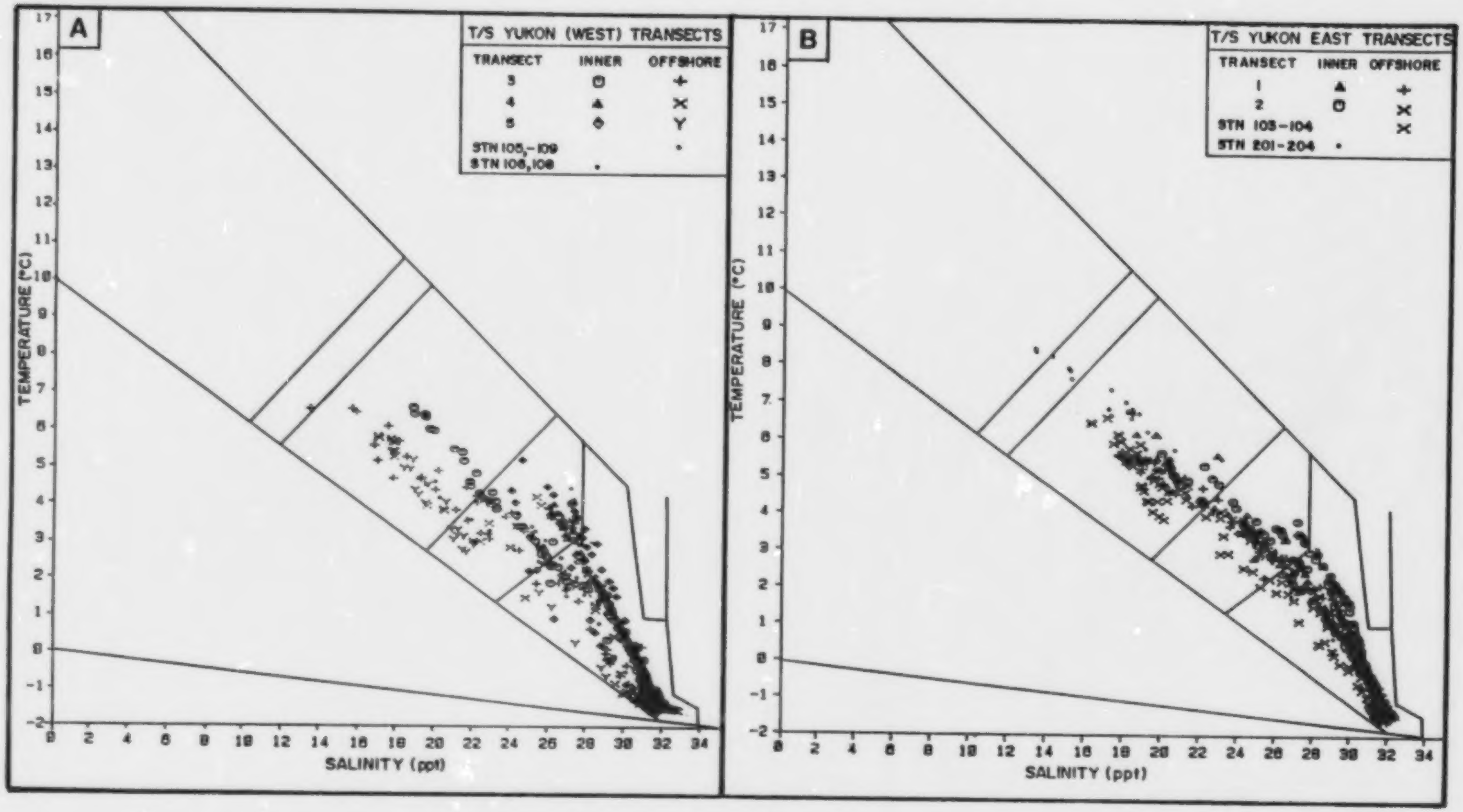


Figure 16. Temperature vs. salinity diagrams of CTD data obtained in Mackenzie Bay and off the Yukon coast on (A) western transects 3, 4 and 5; and (B) eastern transects 1 and 2. The water mass boundaries are identical to those labeled on Figure 13.

occurred in the Arctic water type. At the CTD stations along the easternmost transects (particularly 7, 6 and 11), the temperatures in the Arctic water were considerably warmer than along central and western transects. When salinities were 28 to 30 psu, temperatures at most eastern stations were 3.5 to 4.5°C, while temperatures at central stations (transects 8 and 9) typically were -0.5 to 1.5°C. On the western transects, temperatures at this salinity were intermediate, -0.5 to 3.0°C. The warming at the eastern stations would be consistent with direct solar insolation of predominantly ASW present in the surface layer. Such situations are most likely to occur at considerable distances from the Mackenzie Delta in regions outside the Mackenzie River plume. The end members of the mixing lines joining ASW with the warmed water had temperatures of approximately 4 to 4.5°C over salinities ranging from 30 psu (easternmost transect 11) to 27.5 (western transects). For the 1975 observations, Macdonald et al. (1987) noted a similar mixing line with an end member of 5.5°C and 31.0 psu, which was attributed to accumulated solar insolation resulting from the early retreat of ice cover in the Bathurst Polynya.

The warmer temperatures in the east likely result from greater solar insolation, possibly associated with the extensive open water conditions present in mid-August (Fig. 10B). Warming could also be associated with westward advection of warmer water from the much earlier ice clearing in the Bathurst polynya at the entrance to Amundsen Gulf. However the prevailing eastward subsurface currents (Fissel and Birch 1984) and the dominance of northwesterly winds in the latter part of August make this explanation less plausible.

Subsurface Water Mass Distributions

Analysis of Yukon Data.--The vertical cross sections of salinity, temperature and attenuance (Figs. 17 to 21) are useful in examining and defining the spatial distribution of water mass types. Figure 22 summarizes the distributions of water masses along the various transects. Along all five transects oriented perpendicular to the Yukon coast, diffuse plume water was present near the surface over the middle and outer portions of the transects. Only on transect 3 off Kay Point did the diffuse plume water extend inshore to

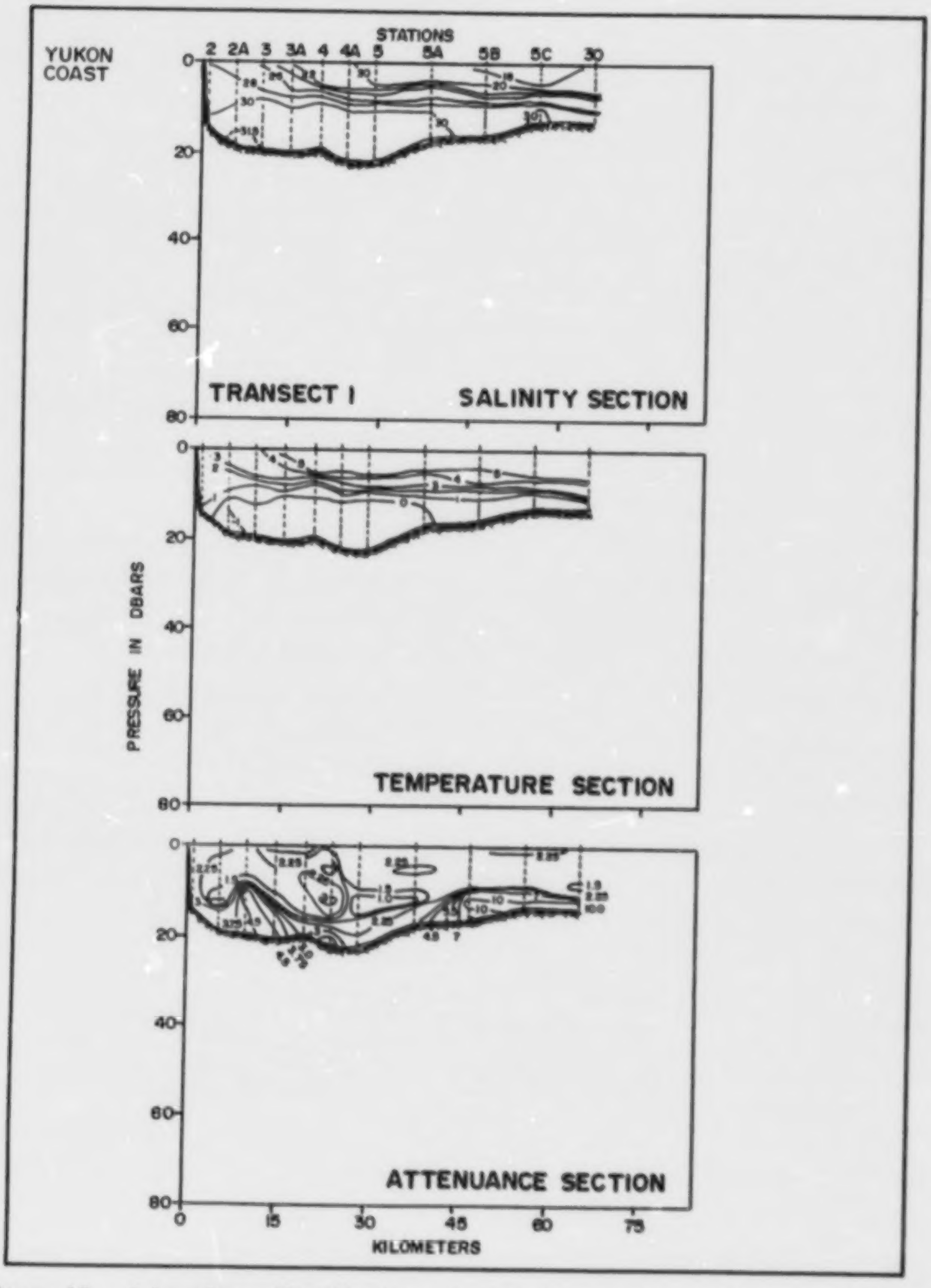


Figure 17. Subsurface distribution of salinity (psu), temperature (°C) and attenuance (m^{-1}) on a vertical cross section extending offshore along transect 1 on 5 September 1986.

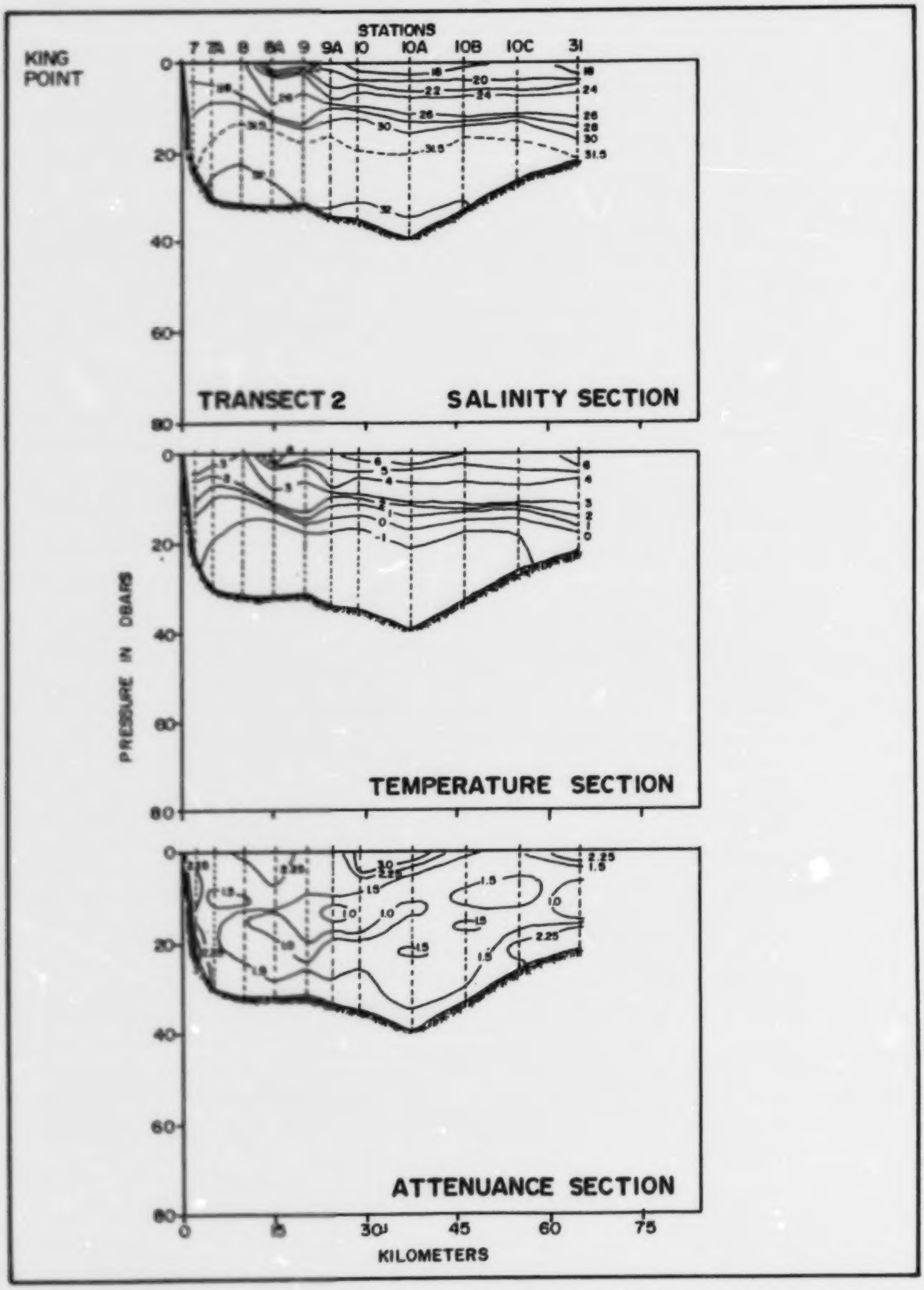


Figure 18. Subsurface distribution of salinity (psu), temperature (°C) and attenuance (m^{-1}) on a vertical cross section extending offshore along transect 2 on 6 September 1986.

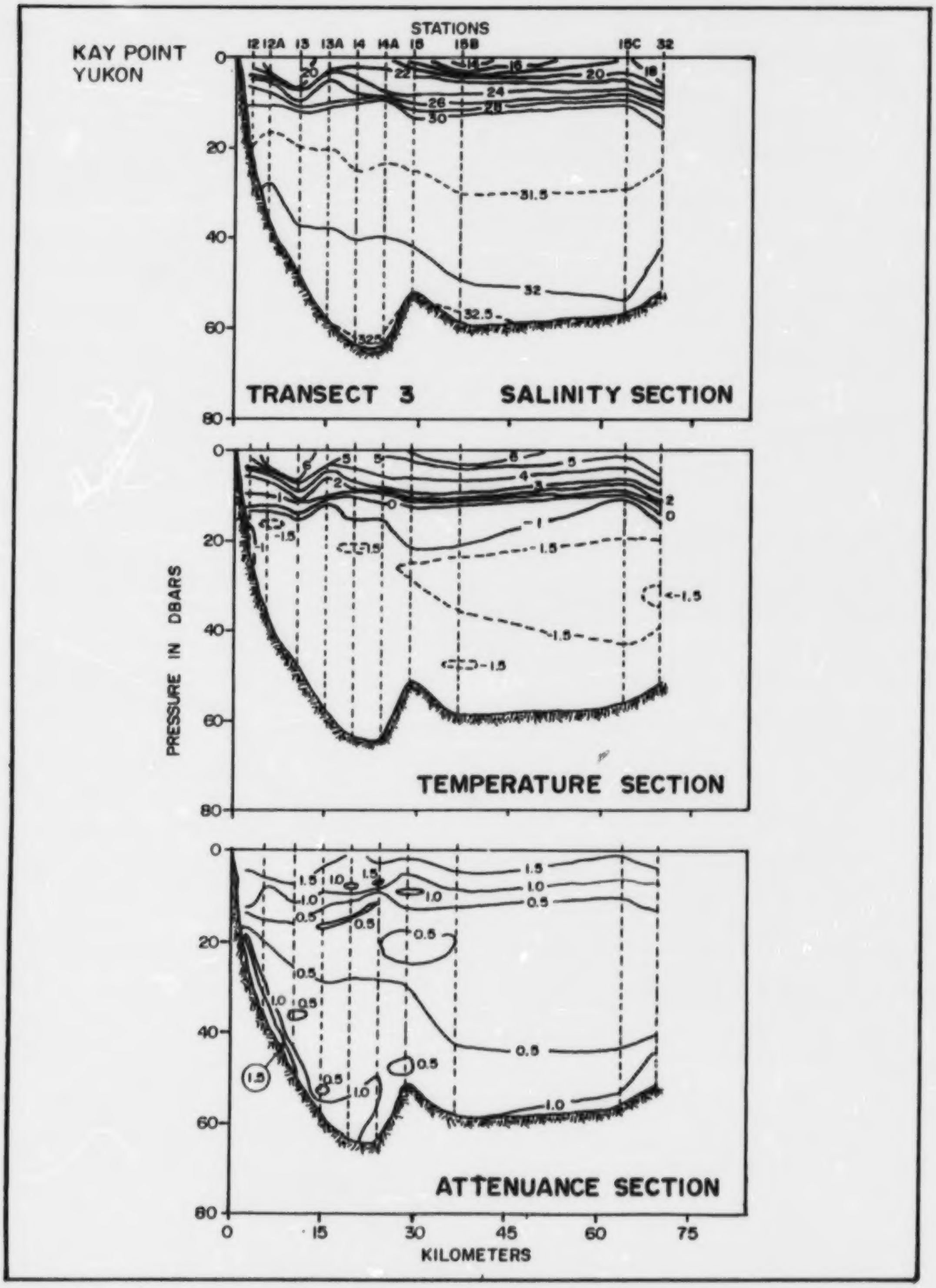


Figure 19. Subsurface distribution of salinity (psu), temperature (°C) and attenuance (m^{-1}) on a vertical cross section extending offshore along transect 3 on 6 September 1986.

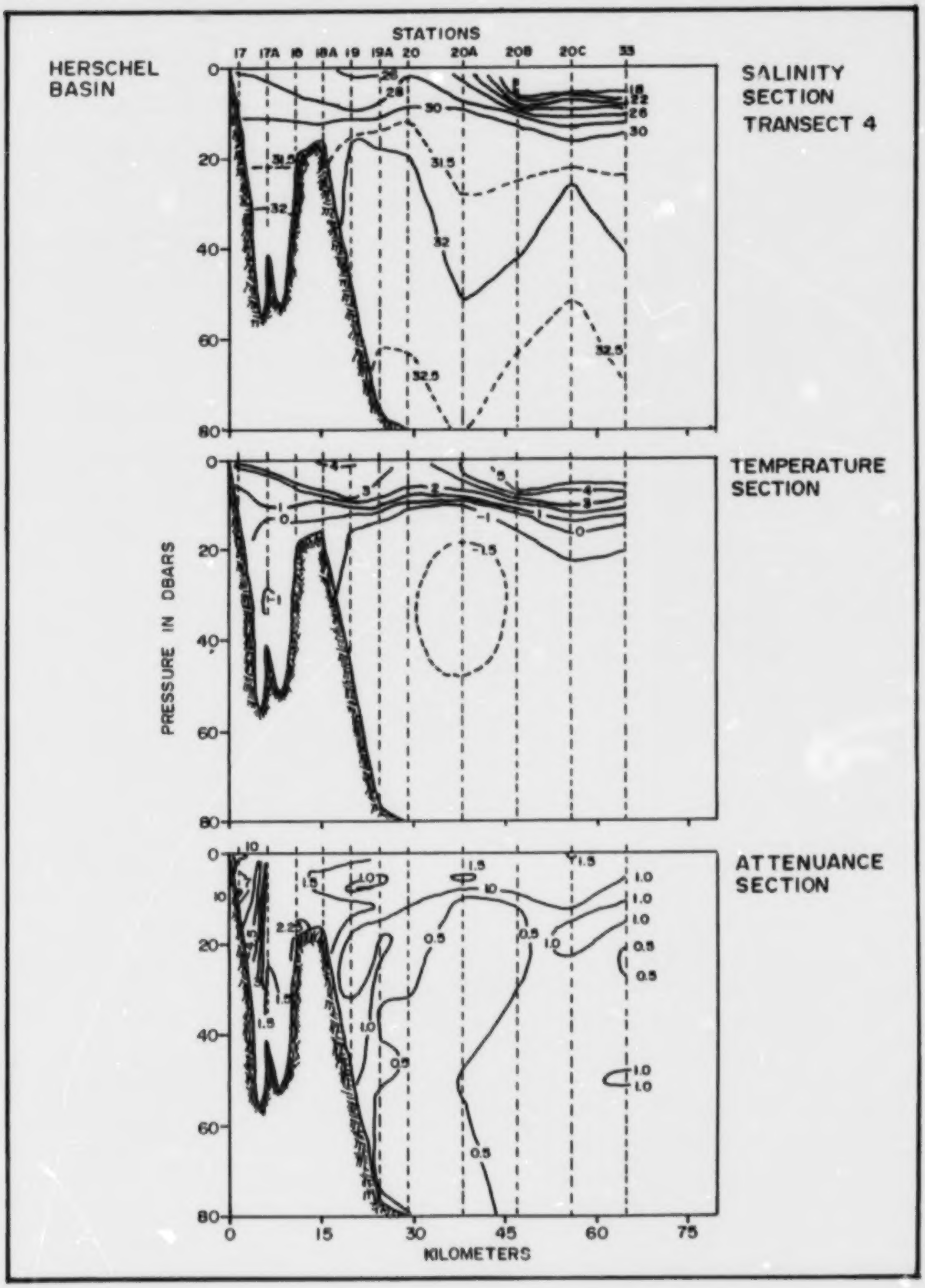


Figure 20. Subsurface distribution of salinity (psu), temperature (°C) and attenuance (m^{-1}) on a vertical cross section extending offshore along transect 4 on 7 September 1986.

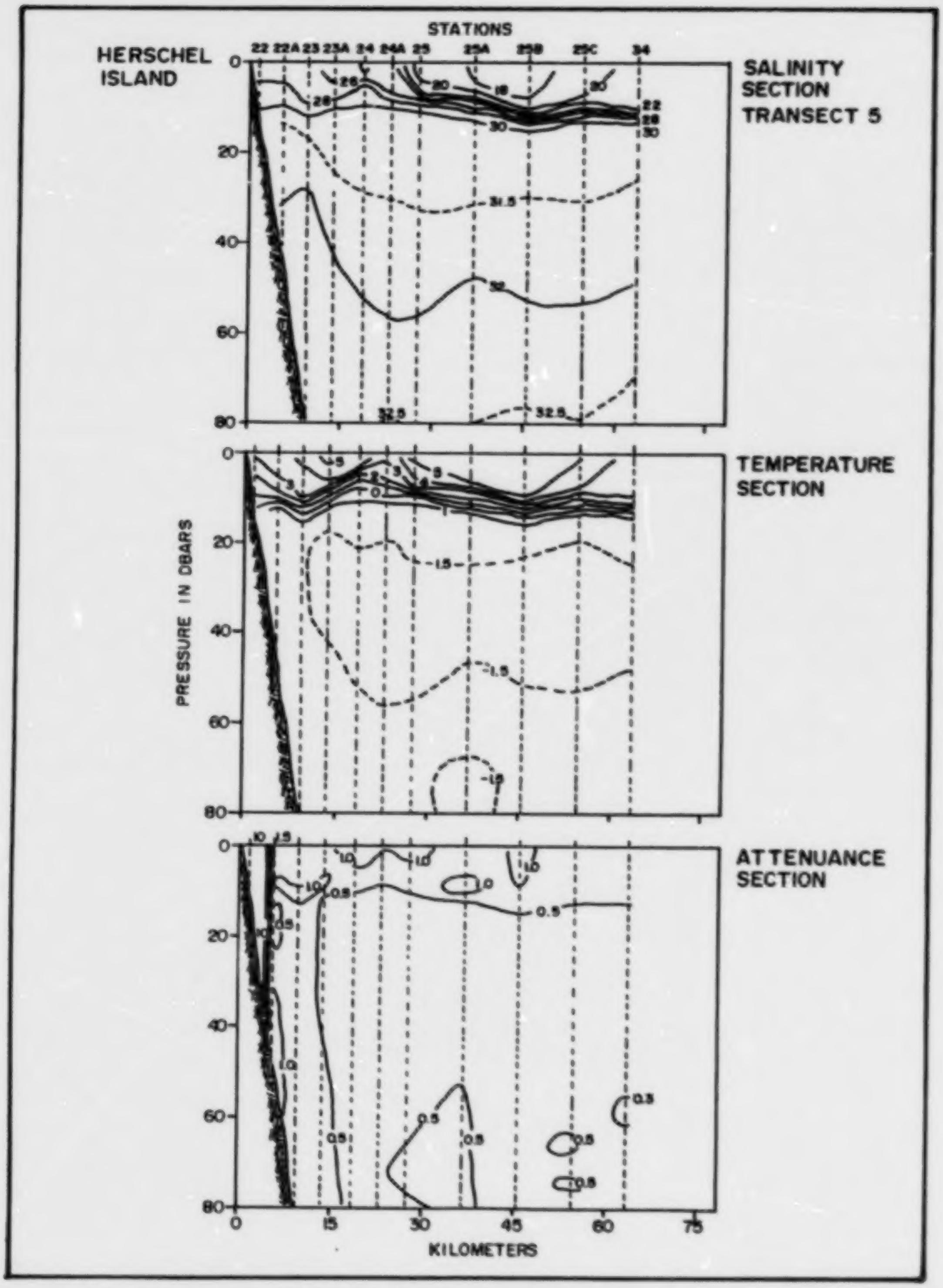


Figure 21. Subsurface distribution of salinity (psu), temperature (°C) and attenuance (m^{-1}) on a vertical cross section extending offshore along transect 5 on 7 September 1986.

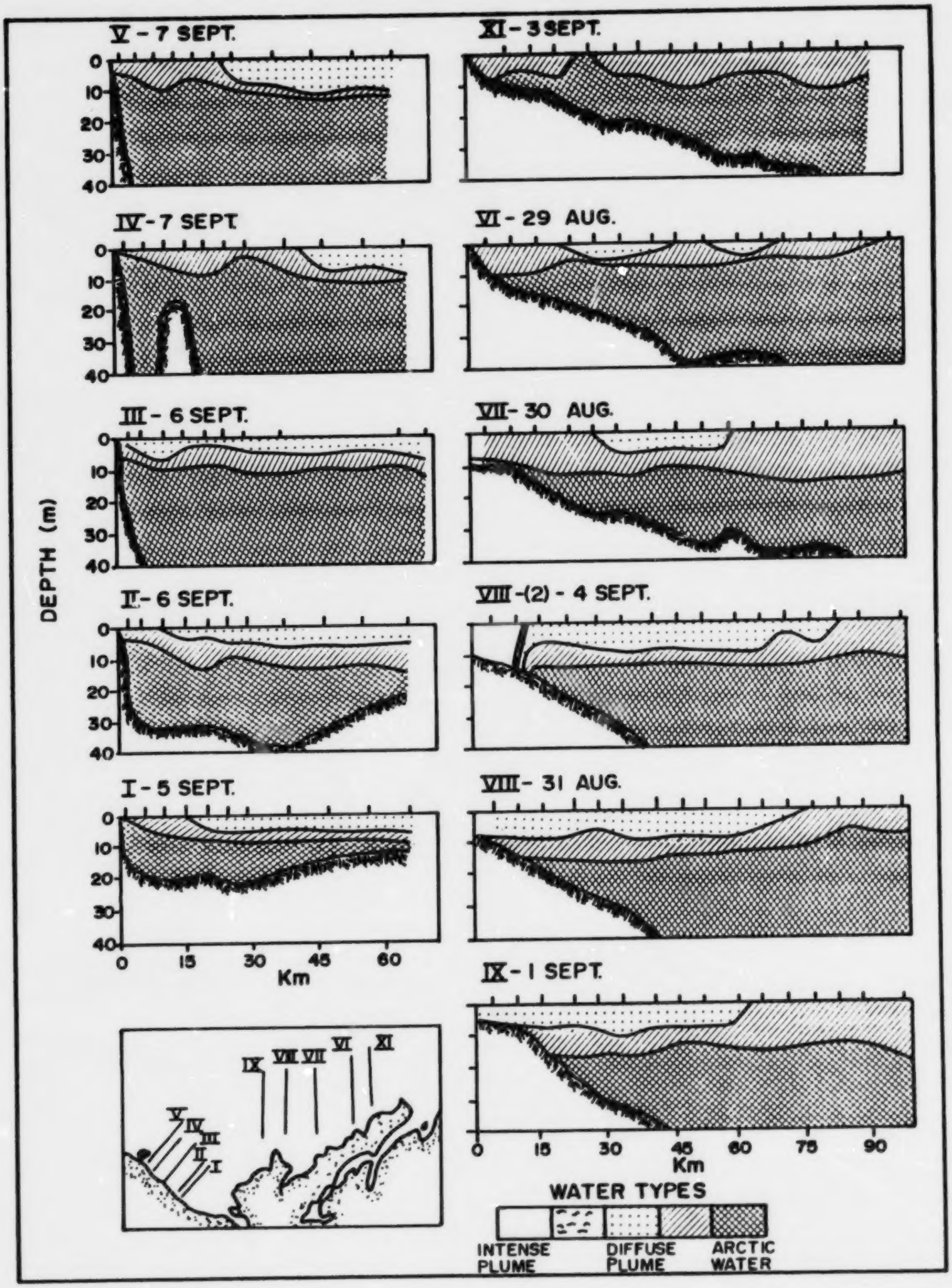


Figure 22. Water mass types within the upper 40 m on vertical cross-sections of all transects.

the coast, and even there the core of the diffuse plume occurred in the middle of the transect (station 15B) over 35 km from the coast (Figs. 19, 22). On both transects 2 and 3, the diffuse plume occurred as two cores of warmer lower salinity water (T>6, S<18) separated by comparatively cooler and more saline water. On both transects, the inner core was located between 30 and 45 km from the coast, while the outer core was situated some 70 km offshore, at the transect's most seaward measurement site. The diffuse plume water extended downward to depths ranging from 2 m (station 8A) to 8 m (stations 25A, 25B, 25C and 34) with typical values of 5-6 m.

Arctic water was present on all transects at stations where depths exceeded 10 to 15 m. Arctic water (or water influenced by Arctic water) extended up to the surface at coastal measurement sites on transects 1, 2 and 4; this surface manifestation of Arctic water extended offshore to distances of 15, 12 and 45 km, respectively. On transect 3 located off Kay Point, the Arctic water also rose to within 2-4 m of the surface at stations 12 and 12A, located 2 and 5 km from the coast. On transect 5, Arctic water rose to within 4-5 m of the surface at stations 22 and 22A, located 2 and 6 km from the coast. The 28 psu isohaline, which best marks the Arctic water boundary off the Yukon coastline, was at or near the surface at coastal stations, but typically was at 10-15 m depth in the middle and offshore portions of each transect. The upward displacement of Arctic water near the coast suggests that there was either shallow upwelling or lateral advection of Arctic water along the coast in early September 1986.

At depths exceeding about 20 m, the temperature and salinity characteristics exhibited little spatial variability. A small amplitude temperature minimum, with temperatures as low as -1.58°C occurred at most middle and offshore sites, particularly on transects 3 and 5. This weak temperature minimum generally occurred at depths of 20 to 40 m and salinities of 31.5 to 32.0 psu. There was no evidence of Bering Sea Water; if present, it would form a temperature maximum at salinities of 30.5 to 32.5 psu, as observed during September 1986 in the Eastern Alaskan Beaufort Sea (Fissel et al. 1987).

The distribution of temperature and salinity at depth provides inconclusive evidence as to the occurrence of large scale upwelling over the Yukon continental shelf in 1986. On two of the Yukon transects (3 and 5), the 31.5 and 32.0 psu isohalines exhibited a general upward tilt toward the coast. However, on the intervening transects 2 and 4, these same isohalines did not exhibit a consistent upward trend toward the coast. The only upward trend of isohalines was limited to much shallower depths (less than 20 m) in the uppermost portion of the Arctic water, as discussed previously. The variability in isohaline patterns among the transects off the Yukon coast suggests that classical wind-driven upwelling either was not occurring or was modified and variable over comparatively small scales (10 to 15 km) as a result of other physical mechanisms.

An intense pycnocline was present along most transects. The pycnocline was most intense immediately beneath the diffuse plume water, where it appeared as a sharp transition to Arctic water T/S characteristics. The magnitude of the vertical gradients in T/S sometimes varied considerably between adjoining stations--on transect 1, for example, compare the very large gradients in the pycnocline at sites 5A and 5C with the weaker gradients at the intervening site 5B. At many locations, particularly on transects 1, 2 and 3, the pycnocline occurred as two separate gradients with much reduced gradients in between. The intervening water separating the dual pycnocline had T/S characteristics that were intermediate between diffuse plume and Arctic water. On transect 1, it had T/S values centred on 3.5°C, 27 psu (site 5A). The intermediate diffuse plume/Arctic water was more extensive on transects 2 and 3, where it was characterized by temperatures of 3 to 5°C and salinities of 22 to 26 psu. Diffuse plume/Arctic water having a similar range of T/S values also occurred on transects 4 and 5, but as a near-surface layer present generally over the inner half of each transect (Figs. 20-22).

The attenuance levels within the diffuse plume waters varied considerably, generally decreasing with increasing distance from the Mackenzie Delta, from >3.0 m^{-1} (transect 2) to <1.0 (transect 5). On transect 1, maximum attenuance levels did not correspond to maximal diffuse plume T/S characteristics. Very large (c>10) attenuance values occurred at depth in the

Arctic water, while values in the diffuse plume (1.5-2.25) were comparable to or lower than those measured on transect 2.

Attenuance levels in the Arctic water included both high and low values. At the shallow measurement sites near the coast (within 2 km), where Arctic water occurred near the surface, large attenuance values occurred. The maximum attenuance level at the coastal sites appeared to vary approximately inversely with water depth. For example, attenuance maxima were 26 and 22 at stations 17 and 22 (water depths of 5 and 7 m) but 2.8 and 3.3 at stations 7 and 12 (water depth 12 m). This pattern, along with the common occurrence of maximal attenuance values at or near the bottom, indicates that these high attenuance values in nearshore areas were of local origin due to resuspension of bottom sediments in shallow coastal locations. The large near-bottom attenuance levels observed in Arctic waters at offshore sites on transect 1 (stations 5B, 5C and 30) were also likely due, at least in part, to the shallow water depths (7-9 m). However, the proximity of these sites to the intense plume (usually within 10-20 km) may also have been a contributing factor.

At measurement locations away from the shallow coastal and near-delta sites, the attenuance levels in the Arctic water were much lower. Attenuance was low through most of the water column, and slightly higher in the near-surface and near-bottom layers. Mid-depth attenuance levels were typically near 0.5 m^{-1}, except at the shallower stations (30-40 m depth) along transect 2, where typical levels were just over 1.0 m^{-1}. The higher levels on transect 2 may represent enhancement of vertical fluxes from diffuse plume water in the surface layer. A near-bottom maximum in attenuance was observed at the majority of measurement sites on all transects. At the deeper sites, in water depths exceeding 30 m, the vertical extent of the near-bottom "turbid" layer can be considerable, up to 15 to 30 m, although the absolute magnitude of attenuance there was low, rarely exceeding 1.0 m^{-1}.

In summary, diffuse plume water was generally situated over the outer half of the continental shelf off the Yukon coastline. The plume extended northwest over the axis of the Mackenzie Trough. There was no evidence of a progressive dilution of diffuse plume water with increasing distance from the

Mackenzie Delta. In fact, the diffuse plume appeared to be more concentrated on the offshore portion of the westernmost transect 5, where it extended to greater depths (up to 10 m) than observed elsewhere off the Yukon Coast. Inshore of the diffuse plume, the upper layer consisted of cooler, more saline water which extended up to 45 km offshore. Very cold and saline Arctic water, generally confined to depths exceeding 10-15 m at offshore locations, was located at or near (within 5 m) the surface at stations within 10 km of the coast. The pycnocline beneath the upper layer was most intense beneath the diffuse plume on the outer shelf, where a sharp vertical transition occurred from diffuse plume to Arctic water at depths of 5 to 15 m. On the three transects situated nearest Mackenzie Bay, two distinct pycnoclines were often observed beneath the diffuse plume. Inshore of the diffuse plume, the pycnocline was much less intense, particularly at sites within 10 km of the coast, where Arctic water nearly extended to the surface. The Arctic water present at or near the surface along the coast did not originate from depth over the central and outer continental shelf, as would be expected from large-scale wind-driven upwelling. If upwelling was occurring at all, it appeared to be limited to depths of 20 m or less, as indicated by the absence of upward tilting isohalines below this level.

Mackenzie Shelf Vertical Sections.--Diffuse plume water was present along all Mackenzie shelf transects except the easternmost transect (11), where the surface layer consisted of colder and more saline waters (Fig. 22-28). The diffuse plume water exhibited a pattern of increased spatial extent and intensity from east to west. On transect 6, the second-most easterly transect, the diffuse plume water occurred in two comparatively narrow bands (15 and 25 km) with minimum salinities of 19.3 (Fig. 23). On transects 8 and 9, located farther to the west off Richards Island, the diffuse plume had a width of more than 60 km, with minimum salinities less than 17.

Intense plume water was not observed on transects 8 and 9 north of Richards Island, indicating that it was confined to locations inshore of the shallowest measurement sites, which were located approximately 24 km from the coast. However, when transect 8 was reoccupied a second time four days later (4 Sept.; designated as transect 8-2), intense plume water was measured at sites 61-2 and 61A-2, situated approximately 24 and 29 km from the coast

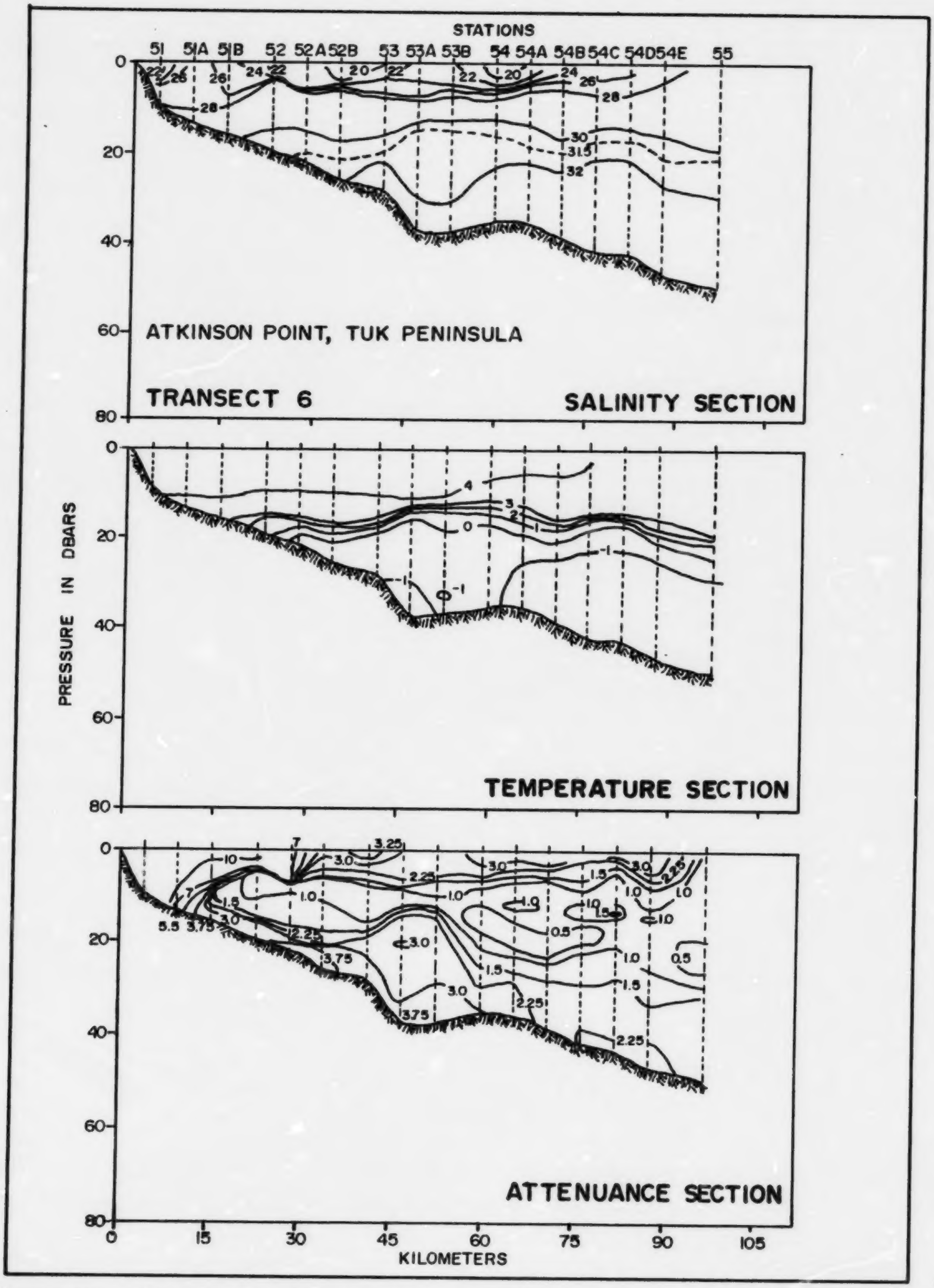


Figure 23. Subsurface distribution of salinity (psu), temperature (°C) and attenuance (m^{-1}) on a vertical cross section extending offshore along transect 6 on 28-29 August 1986.

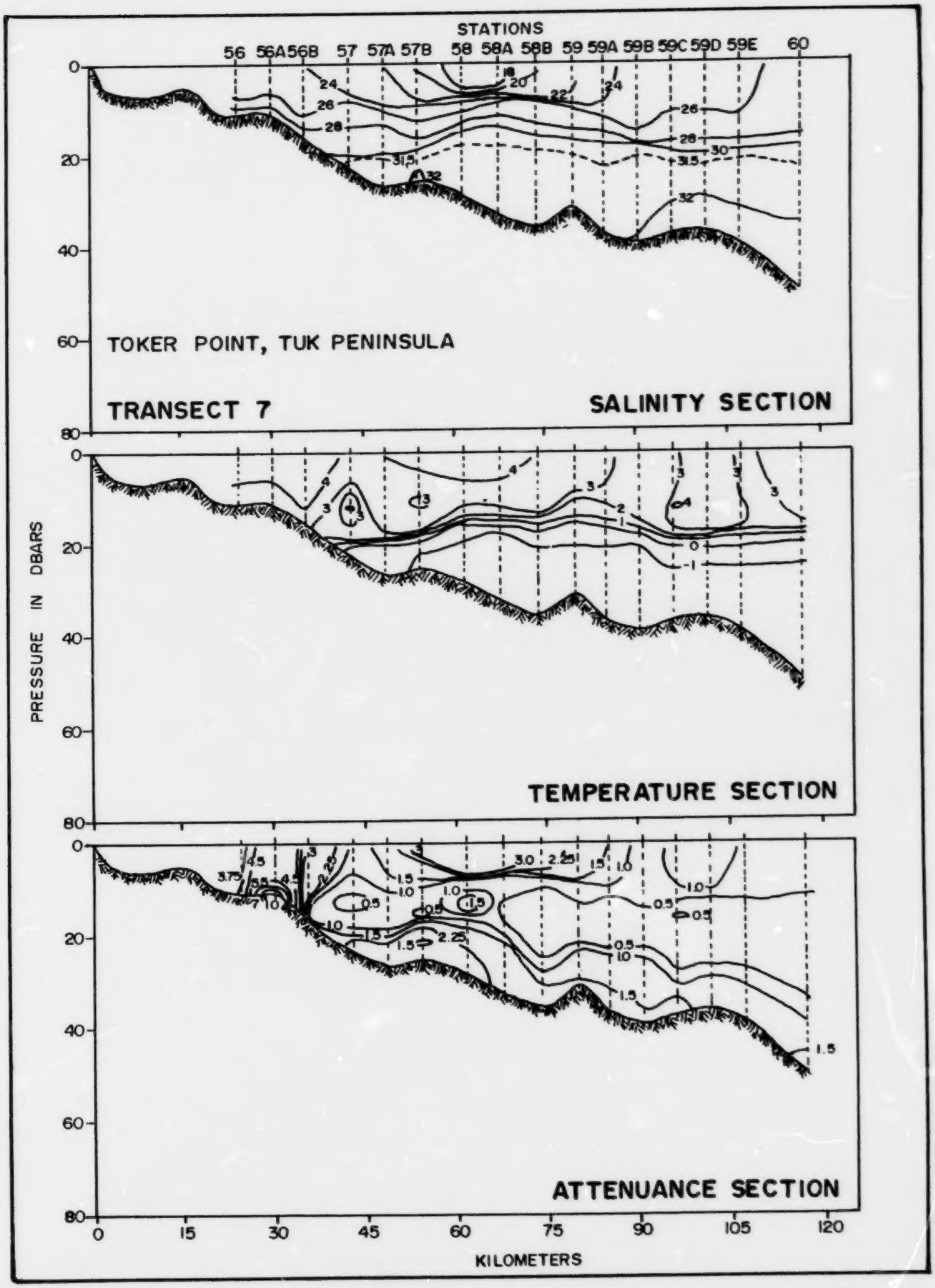


Figure 24. Subsurface distribution of salinity (psu), temperature (°C) and attenuance (m^{-1}) on a vertical cross section extending offshore along transect 7 on 30 August 1986.

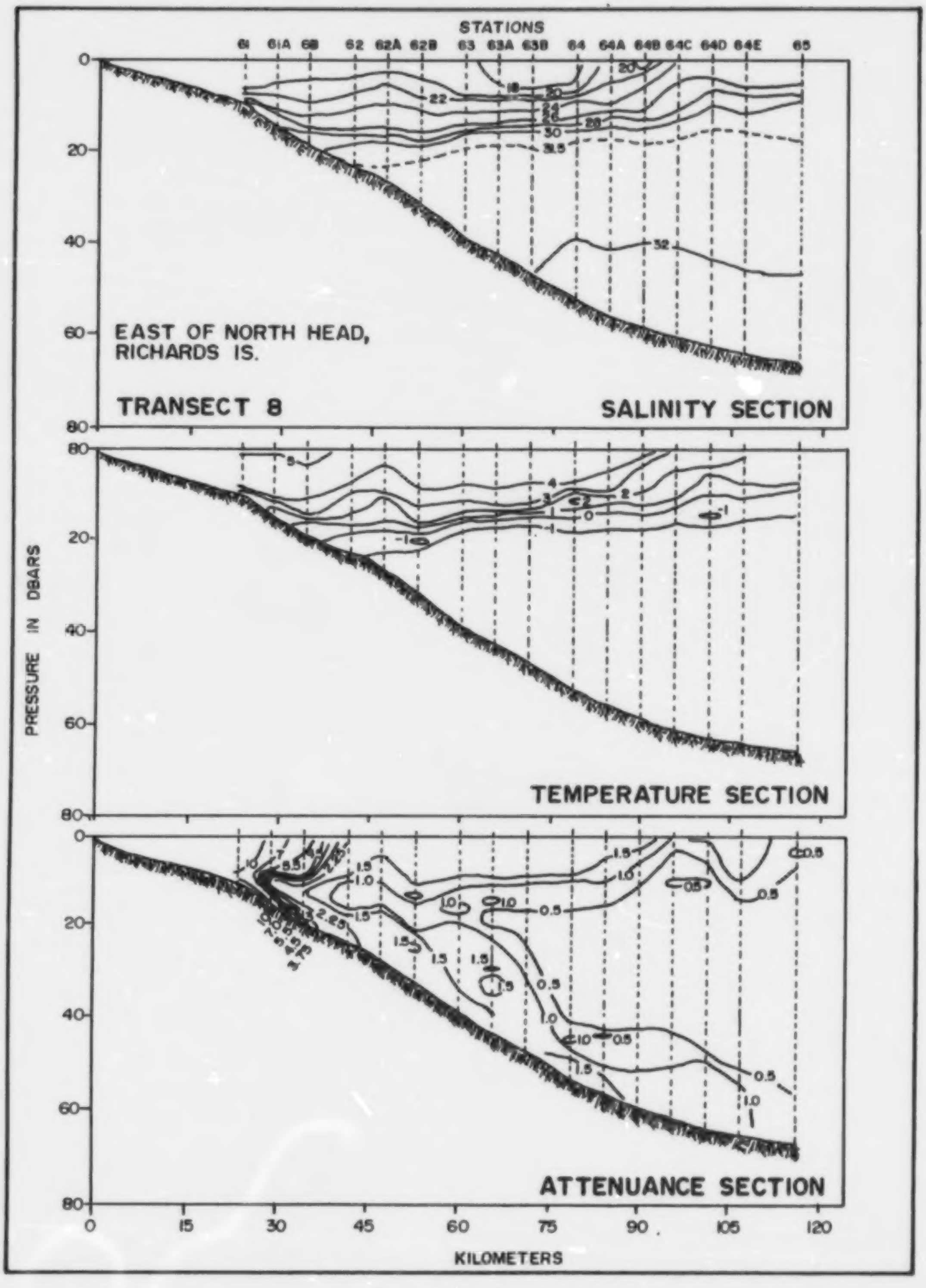


Figure 25. Subsurface distribution of salinity (psu), temperature (°C) and attenuance (m^{-1}) on a vertical cross section extending offshore along transect 8 on 31 August 1986.

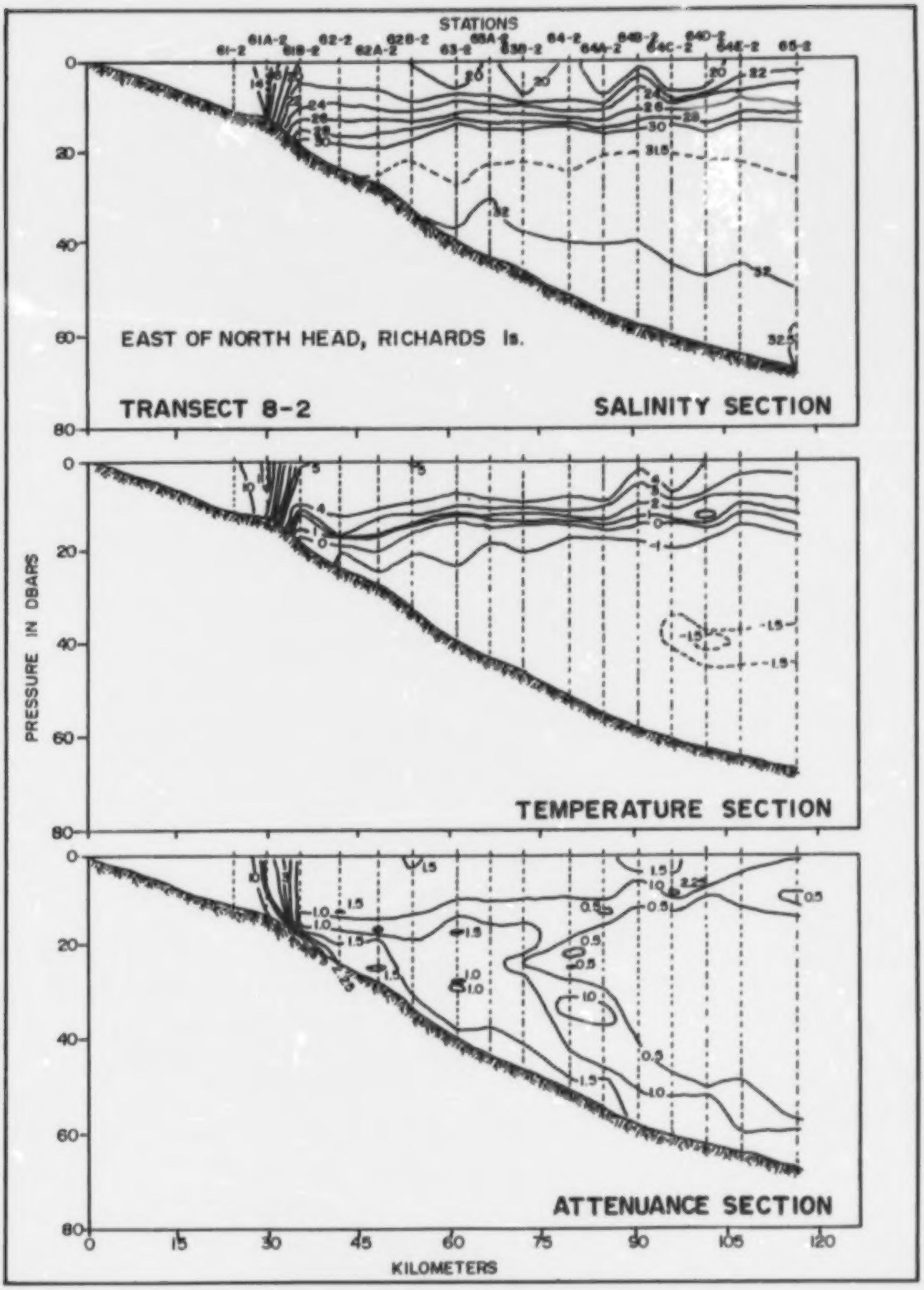


Figure 26. Subsurface distribution of salinity (psu), temperature (°C) and attenuance (m^{-1}) on a vertical cross section extending offshore along transect 8-2 (second occupation of transect 8) on 4 September 1986.

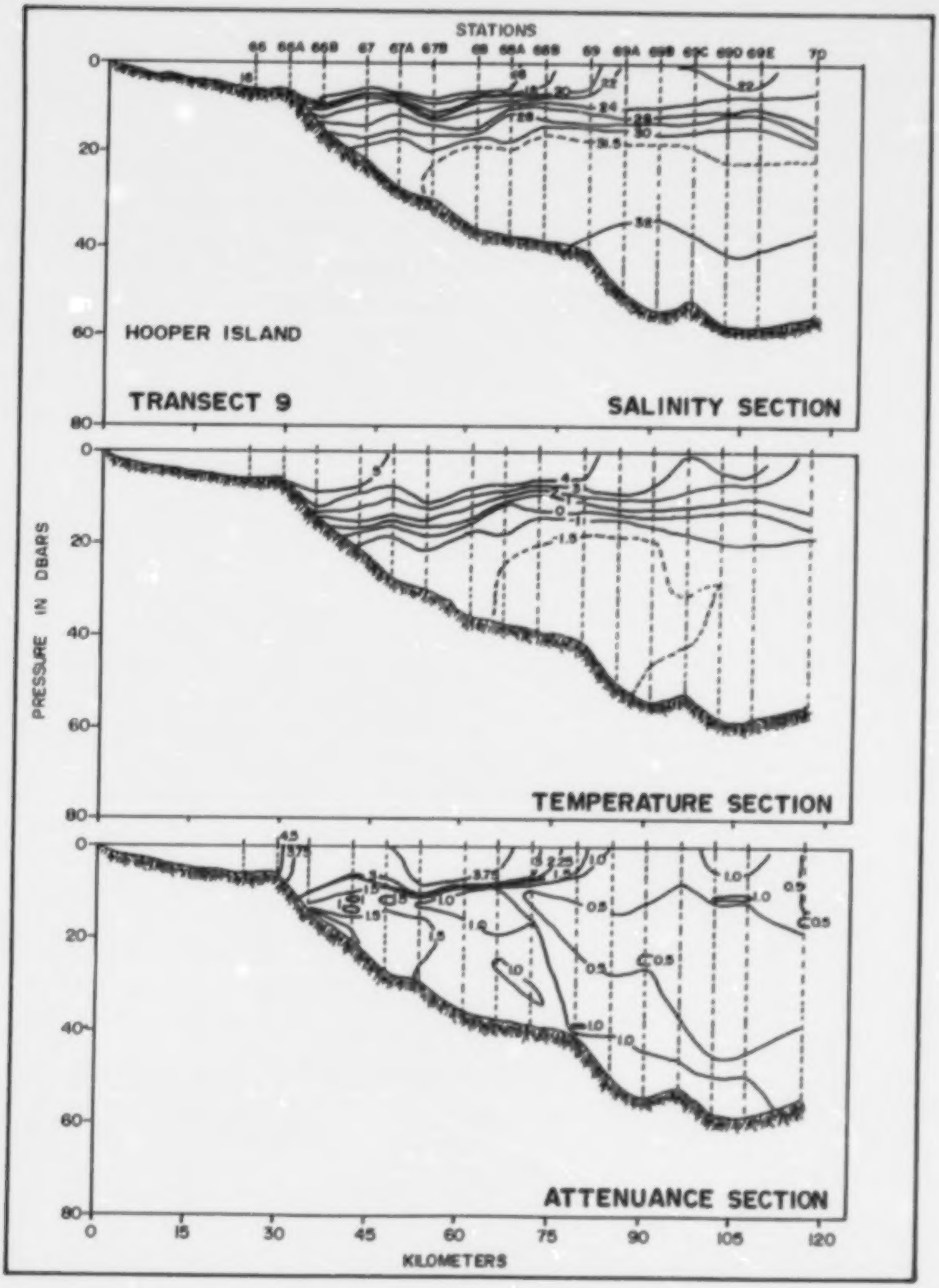


Figure 27. Subsurface distribution of salinity (psu), temperature (°C) and attenuance (m^{-1}) on a vertical cross section extending offshore along transect 9 on 1 September 1986.

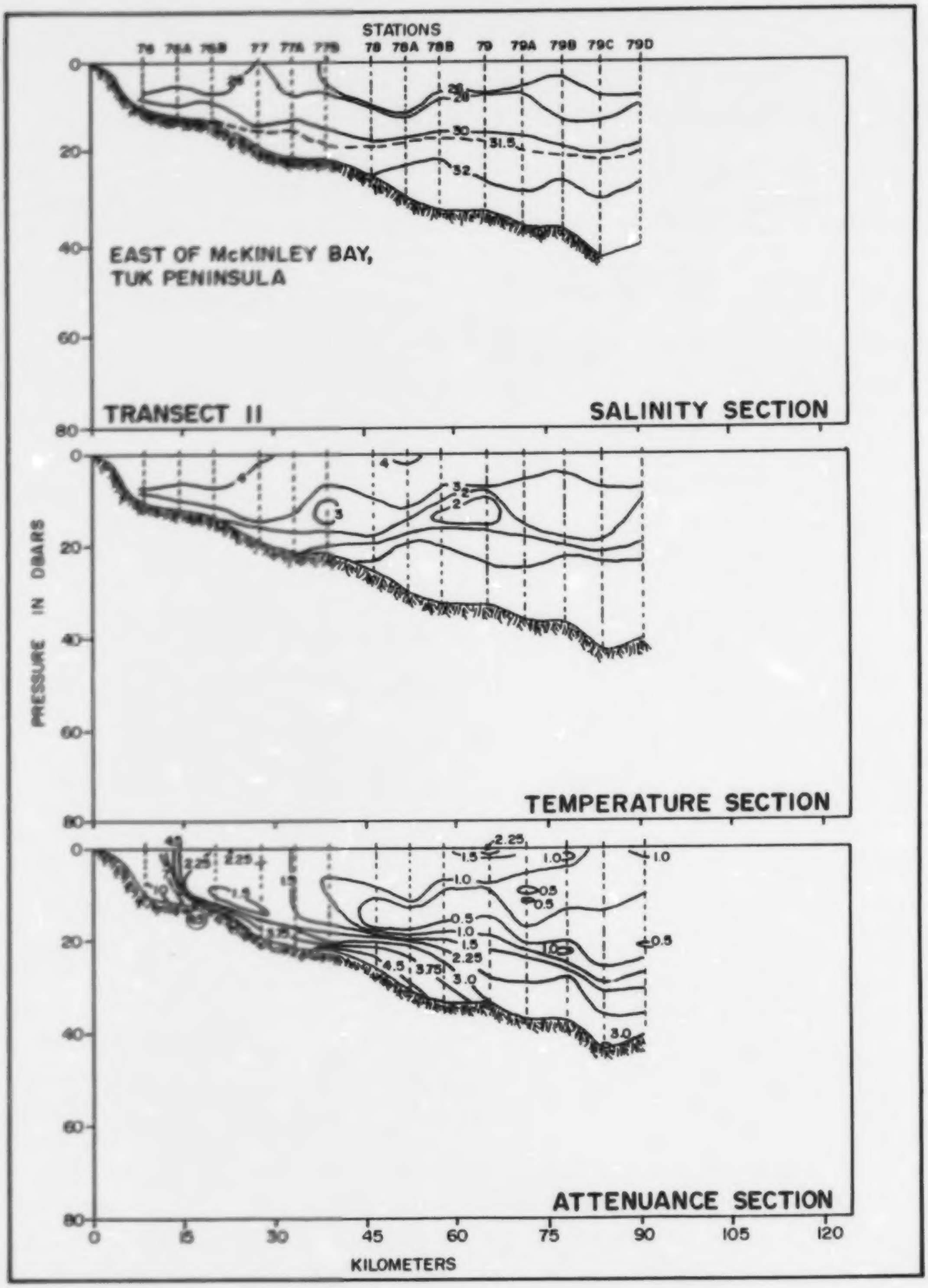


Figure 28. Subsurface distribution of salinity (psu), temperature (°C) and attenuance (m^{-1}) on a vertical cross section extending offshore along transect 11 on 1 September 1986.

(Figs. 22, 26). On this second occupation, the diffuse plume had also been displaced farther offshore to station 64D-2, approximately 100 km north of the coast, and nearly 10 km farther offshore than four days previously.

Arctic water, while present at depths of 20 m or greater on all transects, was not present at the surface at any site on transects 9, 8 or 7. Arctic water was present at the surface at the outermost station on transect 6 and at one station (site 77) on the easternmost transect 11. Unlike the situation off the Yukon coast, Arctic water was not more prevalent at or near the surface at coastal locations. Indeed, on transects 9 and 8, Arctic water was confined to greater depths (14-18 m) at inshore sites than at offshore locations. On the most easterly transects (7, 6 and 11), cooler and more saline water did make up the surface layer at measurement sites nearest the coast; however there was little indication of the shallow upwelling patterns observed off the Yukon Coast.

At depths exceeding 20 m, the Arctic water exhibited weaker but still significant spatial patterns. Among individual transects, there was little consistency in the tilting of isohalines. Upward tilting of isohalines at depth was limited to the second occupation of transect 8 ($S = 32.0$, Fig. 26) and possibly the 31.5 and 32.0 isohalines on transect 11 (Fig. 28). The absence of a more consistent pattern among the various transects suggests that upwelling was not occurring over the Mackenzie Shelf in late August 1986. The modest upward tilt on transect 8-2, and the shoreward advance of the 32.0 isohaline, may be indicative of weak upwelling conditions in early September 1986.

A more consistent pattern was the warmer temperatures at intermediate depths (15-25 m) on the easternmost transects 6 and 11 as compared to the more westerly transects 9, 8 and 7. The difference in upper Arctic water temperatures is particularly striking when examined on salinity surfaces, as shown in Figure 29 for salinities of 28, 30 and 31 psu. The differences were most pronounced on the 28 and 30 psu surfaces where temperatures on transects 7, 6 and 11 were generally 2-3 C° greater than those on either the more westerly transects 9 and 8 or the Yukon transects. On the 31 psu salinity surface, the occurrence of the warmer temperatures was more limited spatially,

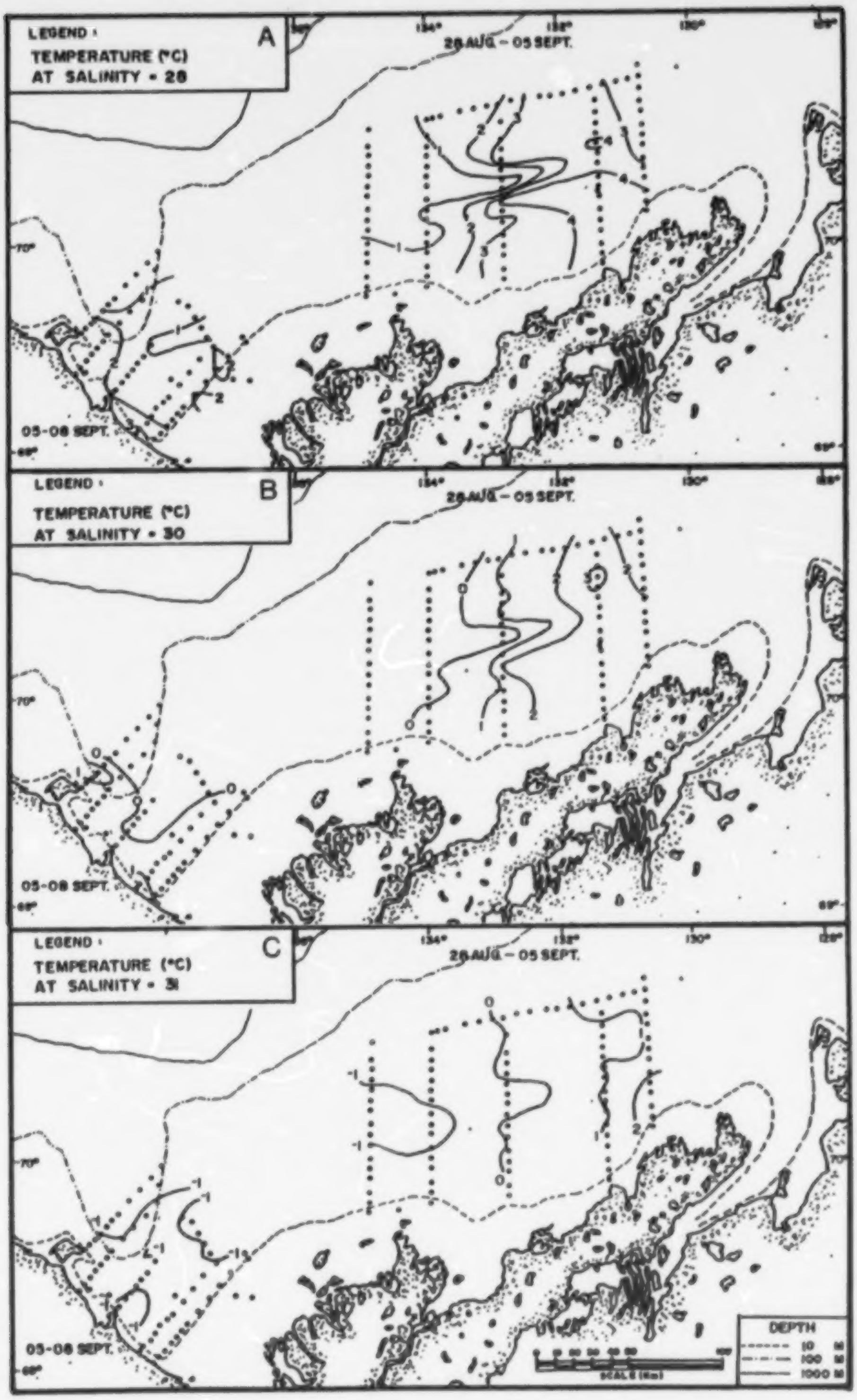

LEGEND:
TEMPERATURE (°C)
AT SALINITY = 28
A
LEGEND:
TEMPERATURE (°C)
AT SALINITY = 30
B
LEGEND:
TEMPERATURE (°C)
AT SALINITY = 31
C
134°
132°
130°
128°
28 AUG - 05 SEPT.
05-08 SEPT.
70°
69°
DEPTH
10 M
100 M
1000 M
SCALE (Km)

Figure 29. Map of temperature on (A) salinity = 28 psu surface, (B) salinity = 30 psu surface, and (C) salinity = 31 psu surface.

being confined to the inner portion of transect 11. In the summer of 1975, the temperatures at 31 psu salinity exhibited a similar pattern (Fig. 12), but with notably more warming at eastern locations, reaching values >4°C near transects 6 and 11. As discussed previously in the "T/S Characteristics" section, the warmer temperatures of this shallow Arctic Water are likely the result of previous solar insolation at the surface and a subsequent descent of the warmed water to subsurface levels.

The pycnocline over the Mackenzie Shelf was most intense immediately beneath the diffuse plume waters at depths of 5-10 m, particularly on transects 9, 7 and 6. At many stations a second and less intense pycnocline also occurred at depths of approximately 15 m, generally coinciding with salinities of 28-30 psu (see Figs. 24, 25 and 27). Separating the two pycnoclines was less stratified water of mixed diffuse plume/Arctic Water characteristics. This water type occurred at the surface on the outer portion of transects 9 and 8, and over larger parts of transects 7, 6 and 11.

The subsurface distributions of attenuance exhibited a reasonably consistent pattern among the Mackenzie Shelf transects. At coastal locations, very large attenuance levels occurred throughout the water column. Attenuance levels of 4.5 or greater appeared to be confined to water depths of 15 m or less. Smaller but still relatively large attenuance values (c>3) were measured in the diffuse plume on transects 9, 7 and 6, but curiously enough attenuance levels in the diffuse plume on transects 8 and 8-2 were lower (c>2.25).

Throughout most of the water column, at sites having water depths of 20 m or more, attenuance levels were greatly reduced. On the outer half of most transects a broad attenuance minimum (c<0.5) extended downward from depths of 15-20 m. However, enhanced attenuance levels of 1.0-1.5 or more did occur as a near-bottom layer at most measurement sites. The vertical extent of this near-bottom enhancement in attenuance was typically 10-25 m. On the easterly transects 6 and 11, the attenuance levels near the bottom were considerably larger (maximum levels of 2.25 to 3.0) than at comparable water depths on transects 9, 8 and 7.

In summary, diffuse plume water was present over more than half the width of the Mackenzie Shelf, in the area north of Richards Island. Here, the diffuse plume occurred in a more concentrated form than observed off the Yukon coast. It was present to depths of 8-10 m over a considerable portion of the Mackenzie Shelf. Farther to the east, the diffuse plume was progressively reduced in area, depth and riverine T/S characteristics. Here the diffuse plume occurred as one or two bands (widths of 15 to 30 km), separated from the coast by cooler more saline water reflecting a greater influence of Arctic water. The diffuse plume did not extend east of McKinley Bay in late August 1986. Over the inner half of the Mackenzie shelf to the north of Richards Island and Kugmallit Bay, Arctic water was confined to depths below 15-20 m, considerably deeper than observed off the Yukon coast or over the eastern portion of the Mackenzie Shelf. Offshore of the diffuse plume, cooler more saline water having intermediate Arctic water/diffuse plume characteristics occupied the surface layer. This water type also occurred as a thin subsurface layer over the inner half of the shelf, separating the diffuse plume and Arctic water. Arctic water occurred at and near the surface only on the easternmost transects 6 and 11. Only on transect 11 did the Arctic water exhibit a distinct upward trend toward the coastline, indicative of upwelling from comparatively shallow depths (<30 m). On the remaining Mackenzie Shelf transects, there was no evidence of upwelling into the upper portion of the water column from depth.

Surface Distributions

Water property distributions within the surface layer over the continental shelf of the Beaufort Sea have been examined in relation to the distribution of bowhead whales in several studies (Borstad 1985; Thomson et al. 1986, Fig. 14; Bradstreet and Fissel 1986; Fissel et al. 1987). Oceanographic features that have been identified as having potential influences on the distribution of bowhead whales are

1. Large scale frontal features separating river-influenced water from the much cooler, more saline Arctic water, and;
2. Areas of apparent upwelling in which nutrient-rich Arctic water has been presumed to have risen from depth.

At least in other areas, frontal features aggregate zooplankton in large quantities, and thus might provide rich feeding areas for whales. Upwelling zones are associated with enhanced levels of productivity, again providing a potential increase in food abundance for whales.

In this study, an extensive set of observations of surface layer distributions were obtained over a 10 day period. The data consisted primarily of 176 profiles of CTD-transmissivity data (29 August-8 September 1986) along with four digitally enhanced pairs of satellite images of temperature and turbidity/attenuance (3, 5, 6 and 8 September). In addition, continuous measurements of temperature and frequent spot measurements of conductivity were obtained near the surface while the vessel was underway. In this section, emphasis is placed on the large scale distribution of water types, while the subsequent section ("Frontal Features") focuses on the locations and characteristics of fronts and their relationships to water property distributions. The CTD-derived data on the surface layer are presented as maps of salinity, temperature and attenuance at the 1.5 m and 5 m levels (Figs. 30 and 31), which roughly correspond to (1) the upper to middle and (2) the lower portions of the surface layer.

Mackenzie Shelf

Surface layer data for the region east of Mackenzie Bay were obtained in two distinct periods:

1. 28 August to 5 September: During this period the CTD-transmissivity data were collected. Most of these data were obtained over a four day period, 29 August to 1 September, when we surveyed transects 6 (with the exception of site 51, sampled on 28 August), 7, 8 and 9. Transect 11 stations were occupied on 3 September followed on 4-5 September by the offshore sites (80 to 91) and a second occupation of transect 8 (8-2).

2. 5 to 8 September: During this period data were derived from a satellite. The entire Mackenzie Shelf region was cloud covered on 3 September, and much of the offshore portion remained under cloud on 5 September. Good viewing conditions prevailed on 6 and 8 September.

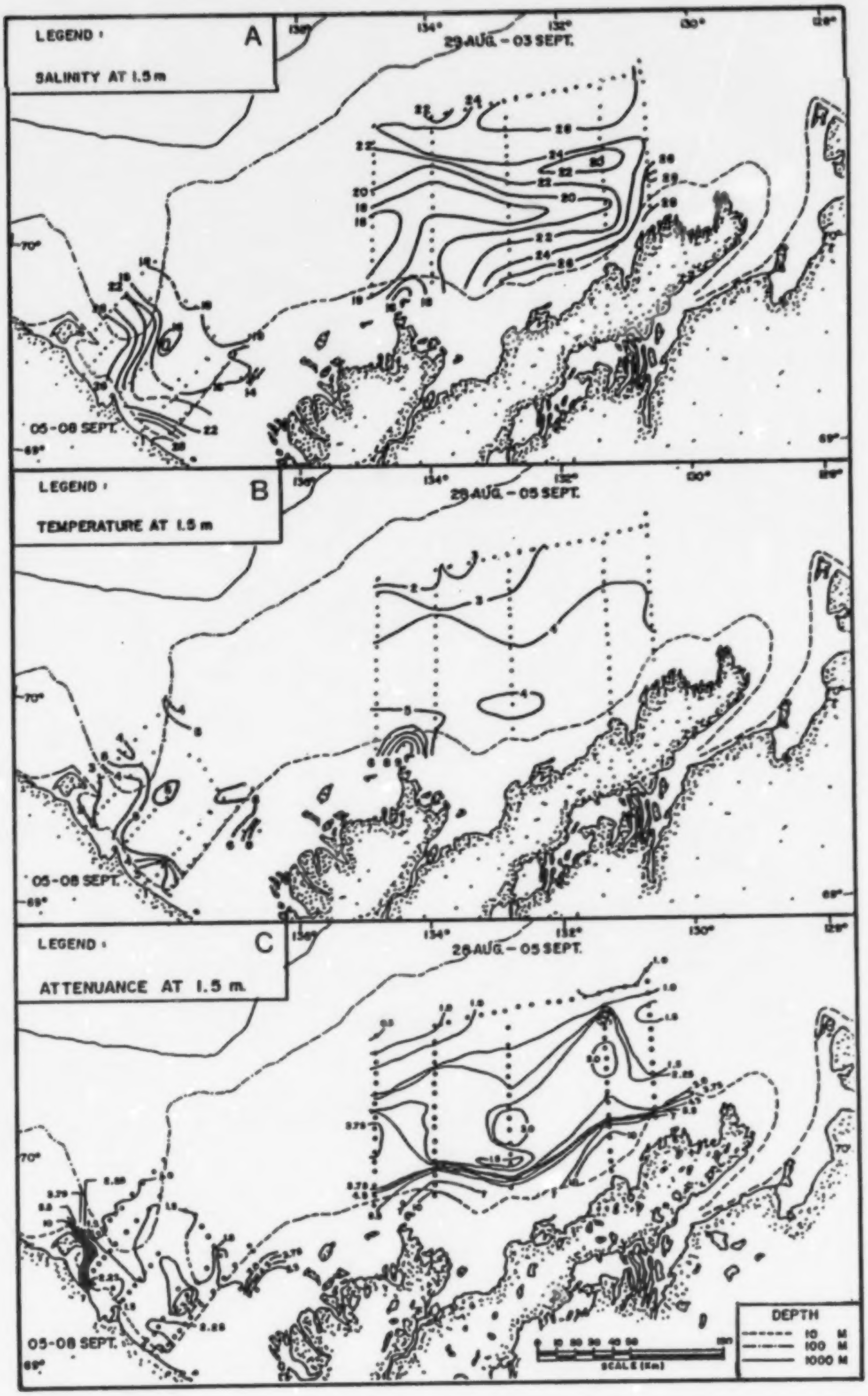

LEGEND :
A
SALINITY AT 1.5 m
29 AUG. - 03 SEPT.
05-08 SEPT.
LEGEND :
B
TEMPERATURE AT 1.5 m
29 AUG. - 05 SEPT.
05-08 SEPT.
LEGEND :
C
ATTENUANCE AT 1.5 m.
28 AUG. - 05 SEPT.
05-08 SEPT.
136°
134°
132°
130°
128°
70°
69°
DEPTH
10 M
100 M
1000 M
SCALE (Km)

Figure 30. Map of (A) salinity; (B) temperature; and (C) attenuance in m^{-1}; at a depth of 1.5 m, as derived from the CTD-transmissiometer data.

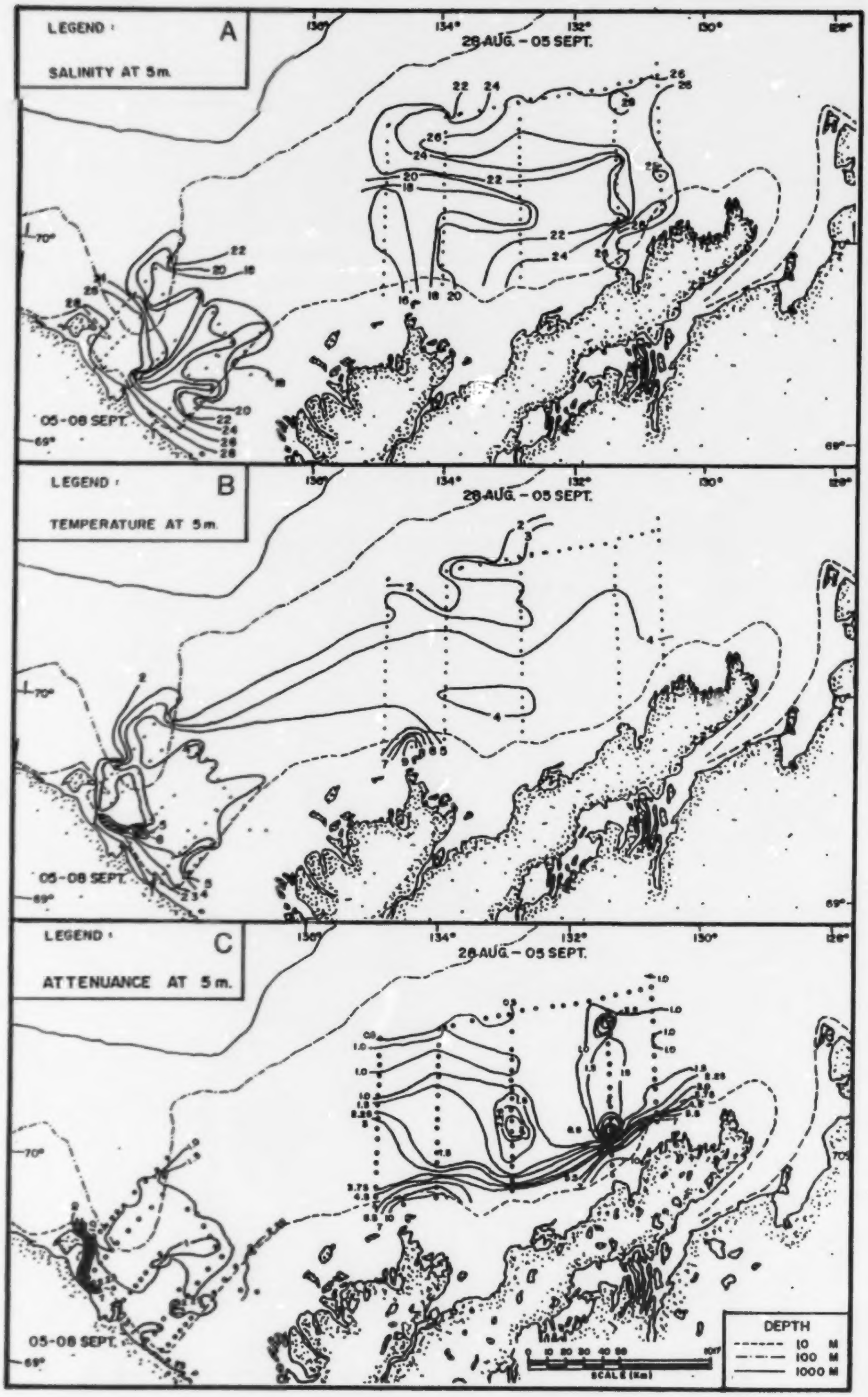

LEGEND :
A
SALINITY AT 5m.
LEGEND :
B
TEMPERATURE AT 5m.
LEGEND :
C
ATTENUANCE AT 5 m.
28 AUG. - 05 SEPT.
05-08 SEPT.
136°
134°
132°
130°
128°
70°
69°
DEPTH
10 M
100 M
1000 M
SCALE (Km)

Figure 31. Map of (A) salinity; (B) temperature; and (C) attenuance in m^{-1}; at a depth of 5 m, as derived from the CTD-transmissiometer data.

During the earlier part of the observational period, primarily from 29 August to 3 September (Figs. 30, 31), the intense plume water appeared to be confined to areas having water depths of 10 m or less, inshore of the shallowest stations sampled from the ship. Measurements of intense plume water were obtained at only two sites: station 97 and station 65-2, located north and northwest of Pullen Island. Both these stations were occupied early on 5 September.

Diffuse plume water, roughly indicated by salinities of 22 psu or less, occupied a large portion of the shelf north of Richards Island and Kugmallit Bay, extending as much as 110 km from the coast. The diffuse plume water appeared to have the form of a core originating in East Mackenzie Bay, with a progressive dilution to the east off the Tuktoyaktuk Peninsula. Here, the diffuse plume water occurred as an offshore band, with a width of approximately 30 km, over water depths of 20-40 m, extending as far east as McKinley Bay (131°W). Farther east, on transect 11, surface layer salinities were markedly greater, and Arctic water was observed in the surface layer at some of the innermost measurement sites. Cooler, more saline water, with characteristics intermediate between Arctic and diffuse plume water, was also present at locations farther west off the Tuktoyaktuk Peninsula, on Transects 6 and 7.

The distribution of surface layer attenuance also exhibited a core of more turbid water extending eastward from north of Richards Island to an area offshore of McKinley Bay. This area corresponds roughly to the diffuse plume distribution inferred from the map of surface layer salinity. Closer to shore, a large scale turbidity front occurred at the surface approximately along the 10-15 m depth contour, extending across at least the full width of the Mackenzie Shelf study area. Horizontal gradients were particularly large on transects 8 (stations 62-62A), 7 (55-55A) and 6 (52A-56B). As a similar large scale boundary was not evident in the T/S distributions, the enhanced turbidities within the inshore region likely resulted from local sediment processes, such as wind-driven mechanical resuspension of bottom sediments, rather than riverine input.

Comparison of the temperature and salinity maps indicates that salinity provided a more detailed representation of diffuse plume characteristics than did temperature (Figs. 30, 31). The temperature distribution was particularly deficient in revealing the presence of Arctic water at the surface on the easternmost transect (11) and at inshore measurement sites off the Tuktoyaktuk Peninsula. This deficiency can be explained from the T/S analyses presented previously; it resulted from the enhanced temperature of the Arctic water in the eastern portion of the Mackenzie Shelf.

The satellite imagery of 5-6 September (Figs. 33, 34) provided the earliest observations of surface temperature and attenuance within the 10 m isobath. Very warm (>8°C) and turbid (>5 m^{-1}) water with intense plume characteristics occurred in East Mackenzie Bay, and in most of Kugmallit Bay.

Diffuse plume water was located immediately offshore and east of the intense plume, extending along the coast of the Tuktoyaktuk Peninsula at least as far east as McKinley Bay (temperature of 5°C or more; Fig. 33). However, the full areal extent of the diffuse plume water on 6 September is more difficult to map accurately, given the previously described ambiguous relationship of surface temperatures (over the range of 3 to 5°C) to the T/S characteristics that define the diffuse plume.

North of Richards Island, surface water temperatures of 5°C or greater extended as far north as 70°20'N. Thus, the offshore limit of the diffuse plume was comparable to that observed on 1 September 1986 using the CTD data from transect 9, but surface temperatures appeared to have warmed by approximately 1 C°. An enhanced influence of diffuse plume water was also evident on the adjacent transect 8 between its first and second occupations on 31 August and 4 September. However, farther to the east, off the Tuktoyaktuk Peninsula (transects 6 and 11), the diffuse plume appeared to be less prominent by 6 September (Fig. 34). On transect 6, the 4°C isotherm was then located much closer to the coast than was the case on 30 August. On transect 11, surface temperatures were below 4°C at all sites on 6 September.

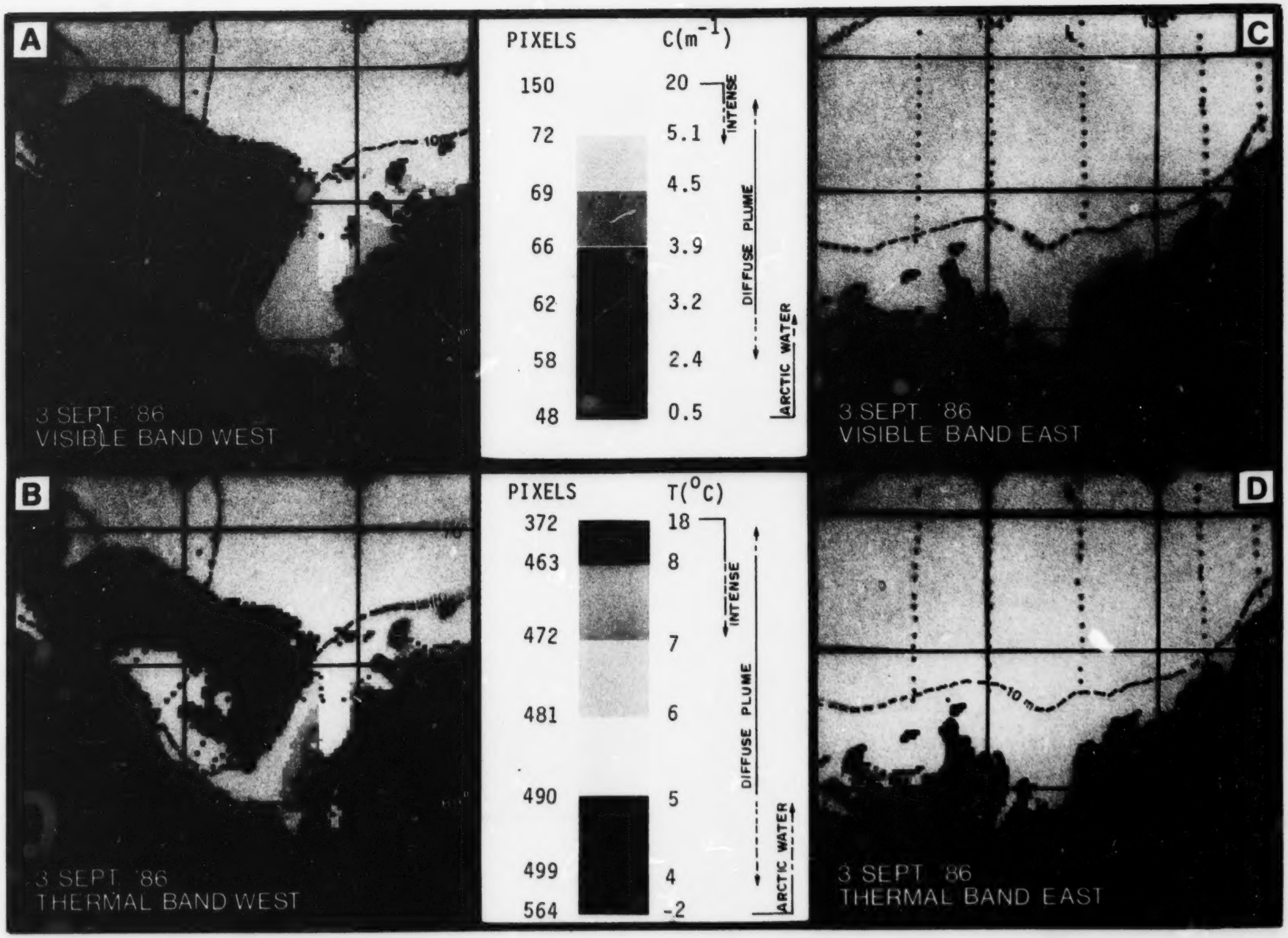

A
3 SEPT. '86
VISIBLE BAND WEST
B
3 SEPT. '86
THERMAL BAND WEST
PIXELS
$C(m^{-1})$
150
72
69
66
62
58
48
20
5.1
4.5
3.9
3.2
2.4
0.5
INTENSE
DIFFUSE PLUME
ARCTIC WATER
PIXELS
T(°C)
372
463
472
481
490
499
564
18
8
7
6
5
4
-2
INTENSE
DIFFUSE PLUME
ARCTIC WATER
C
3 SEPT. '86
VISIBLE BAND EAST
D
3 SEPT. '86
THERMAL BAND EAST
10m

Figure 32. Satellite data for 3 September 1986. In this and other satellite images, white areas represent cloud.

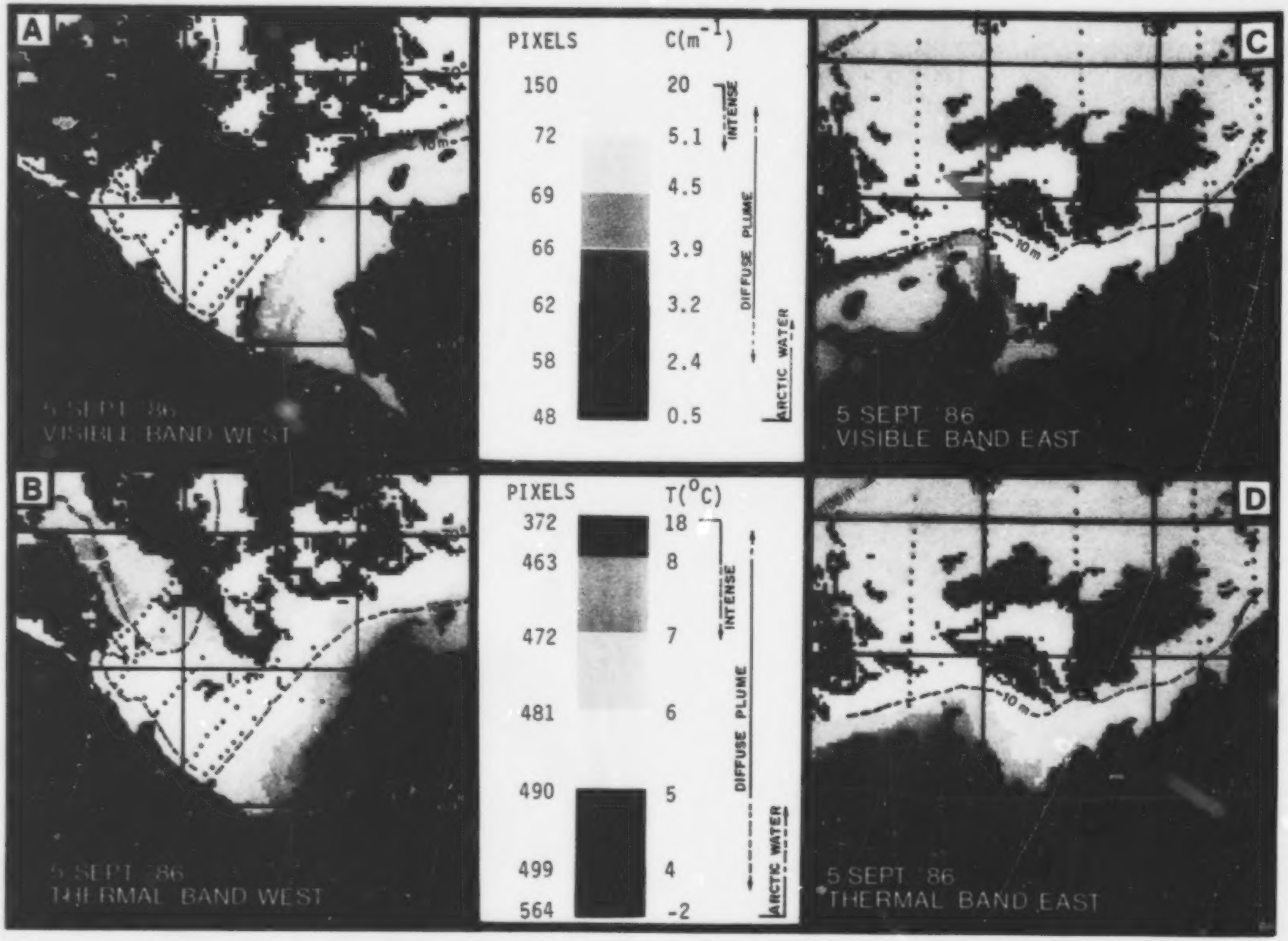

A
5 SEPT '86
VISIBLE BAND WEST
10m
B
5 SEPT '86
THERMAL BAND WEST
PIXELS
C(m^{-1})
150 20
72 5.1
69 4.5
66 3.9
62 3.2
58 2.4
48 0.5
INTENSE
DIFFUSE PLUME
ARCTIC WATER
PIXELS
T(^{o}C)
372 18
463 8
472 7
481 6
490 5
499 4
564 -2
INTENSE
DIFFUSE PLUME
ARCTIC WATER
C
5 SEPT '86
VISIBLE BAND EAST
10 m
D
5 SEPT '86
THERMAL BAND EAST
10 m

Figure 33. Satellite data for 5 September 1986.

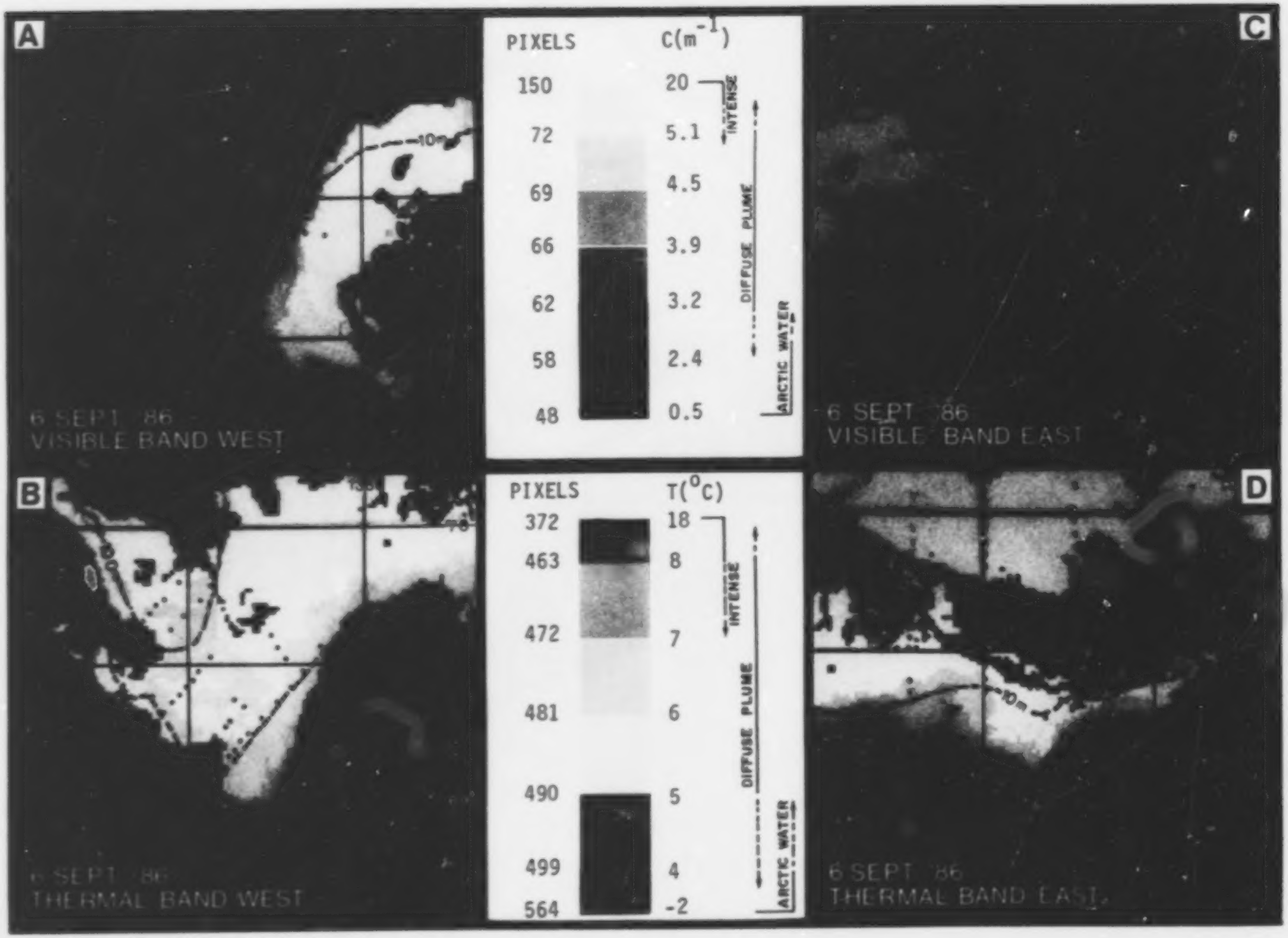

A
6 SEPT 86
VISIBLE BAND WEST
10m
PIXELS
150
72
69
66
62
58
48
C(m^{-1})
20
5.1
4.5
3.9
3.2
2.4
0.5
INTENSE
DIFFUSE PLUME
ARCTIC WATER
C
6 SEPT 86
VISIBLE BAND EAST
B
6 SEPT 86
THERMAL BAND WEST
PIXELS
372
463
472
481
490
499
564
T(^{o}C)
18
8
7
6
5
4
-2
INTENSE
DIFFUSE PLUME
ARCTIC WATER
D
10m
6 SEPT 86
THERMAL BAND EAST

Figure 34. Satellite data for 6 September 1986.

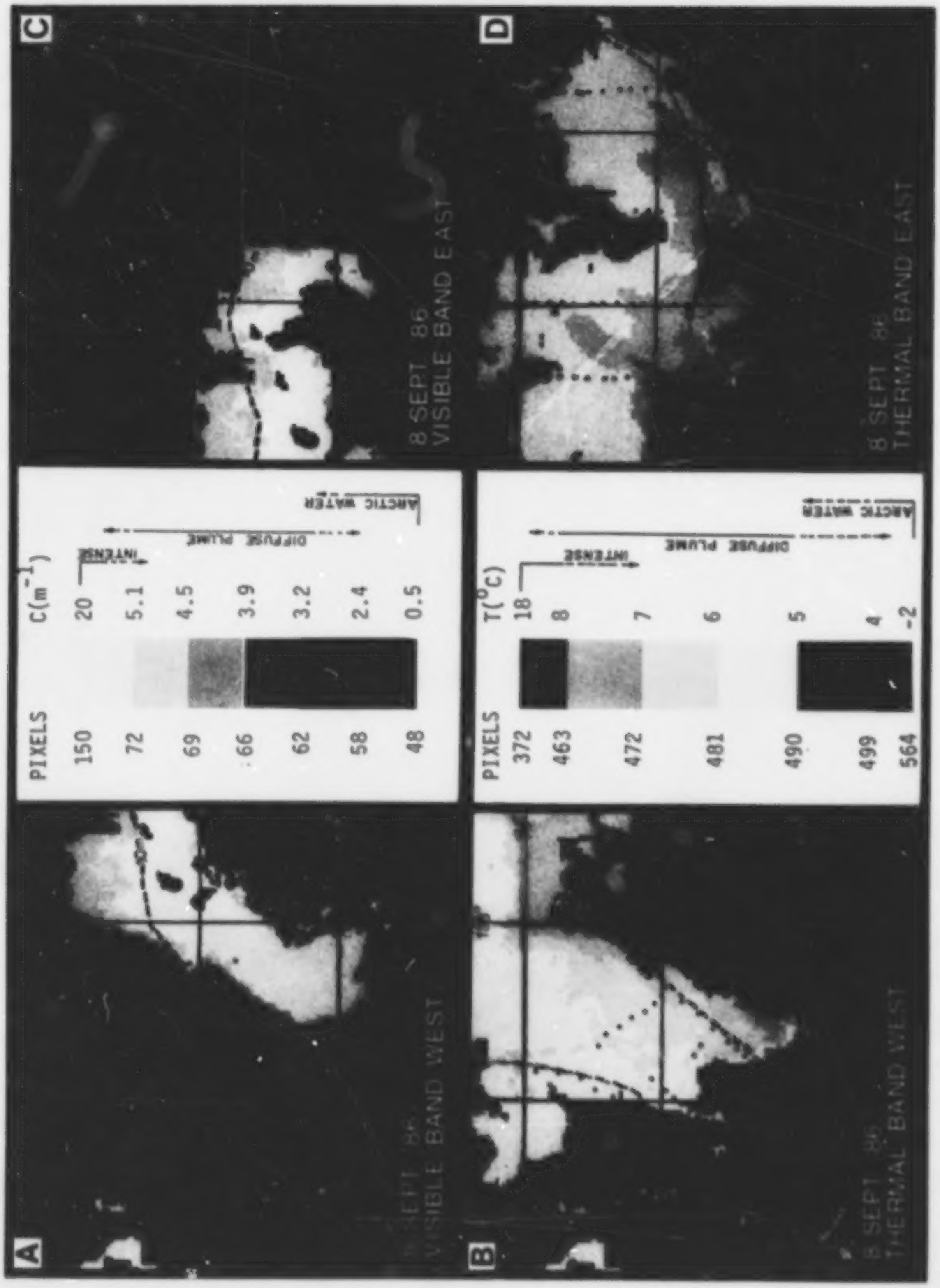

A
8 SEPT. 86
VISIBLE BAND WEST
B
8 SEPT. 86
THERMAL BAND WEST
C
8 SEPT. 86
VISIBLE BAND EAST
D
8 SEPT. 86
THERMAL BAND EAST
PIXELS
C(m^{-1})
150 20
72 5.1
69 4.5
66 3.9
62 3.2
58 2.4
48 0.5
INTENSE
DIFFUSE PLUME
ARCTIC WATER
PIXELS
T(°C)
372 18
463 8
472 7
481 6
490 5
499 4
564 -2
INTENSE
DIFFUSE PLUME
ARCTIC WATER

Figure 35. Satellite data for 8 September 1986.

Within the inshore portion of the diffuse plume, two warm cores (>6°C) with eastward orientation were evident. One core extended from the intense plume past the north end of Richards Island to approximately 134°40'W, over 30 km from the coast (to the vicinity of site 65A on transect 8). This warm core was also accompanied by higher attenuance levels (>3.2 m^{-1}). The second warm core occurred adjacent to the coastline of the Tuktoyaktuk Peninsula between Kugmallit Bay and 132°W, with a typical width of 10 km, and lower attenuance levels (2.4 to 3.2 m^{-1}).

On 8 September 1986 (Fig. 35), the intense plume waters appeared to have changed little in East Mackenzie Bay, and to have been redistributed westward in Kugmallit Bay. In Kugmallit Bay, high turbidity water occurred as a continuous nearshore band, of width 10-20 km, from northern Richards Island to the western half of Kugmallit Bay, but did not extend along the eastern coastline of Kugmallit Bay, contrary to the situations on 6 September 1986. The thermal band data reveal similar changes to those inferred from the visible band, with a broad filament of warm (>8°C) water being observed to extend as much as 40 km offshore from the western side of Kugmallit Bay and noticeably cooler water occupying the eastern half of Kugmallit Bay.

The diffuse plume also exhibited major changes in areal distribution from 6 to 8 September. Off East Mackenzie Bay, Kugmallit Bay and the Tuktoyaktuk Peninsula, the spatial extent of surface waters having moderate temperatures (>5°C) expanded considerably from 6 September. If we consider the 5°C isotherm to be its seaward boundary, the diffuse plume now extended to distances of 80-120 km off Richards Island, nearly twice the distance from shore observed on 6 September. Similarly off the Tuktoyaktuk Peninsula, the 5°C isotherm extended over distances of 40-70 km offshore, while on 6 September it had been confined to a much smaller area, within 15 km of shore. Within the diffuse plume, cores of warmer water (temperatures of 6-7°C) occurred in the form of (1) a broad, 20 km wide band of warm water extending northeast from Kugmallit Bay as far as McKinley Bay, and (2) a tongue of warm water extending as an offshore filament some 40 km beyond the intense plume over a width of 15 km, due north of Richards Island. For the former feature, turbidity levels were low (attenuance <2.4 m^{-1}) and did not correspond to the temperature core, while for the latter feature, enhanced attenuance levels of 2.4 to 3.2 m^{-1} did coincide with the thermal feature north of Richards Island.

Both the intense and diffuse plume waters appeared to follow a general pattern of expansion and offshore displacement from 6 to 8 September. This pattern was consistent with regional wind conditions. Weak winds on 6 September were followed by weak-to-moderate easterly winds on 7 to 8 September. Under the influence of east to southeast winds, a modest offshore displacement would be expected, combined with reduced mixing and resultant warming of surface temperatures, due to the general low intensity of the winds. The lower levels of wind-induced mixing are also consistent with much reduced attenuance or turbidity levels in coastal areas away from the Mackenzie plume, such as the Tuktoyaktuk Peninsula.

Yukon Coast-Mackenzie Bay

In this region, the ship and satellite-based observations largely coincide. Data were collected from the ship on 5 to 8 September, within the 3 to 8 September period of satellite-based data collection. Because of this overlap in the two data types, the description of surface conditions is based in large part on the more detailed spatial coverage of the satellite imagery.

Clouds obscured the eastern portion of the study area on **3 September 1986** but there was good visibility off the Yukon coast (Fig. 32). The seaward boundary of the intense Mackenzie River plume occurred as an intense turbidity front approximately 10 km east of the 10 m isobath. Across this front of width 2-3 km, attenuance increased from less than 2.4 m^{-1} to 5 m^{-1} or more. The pronounced turbidity front coincided with the 5°C isotherm. Surface temperatures increased progressively toward the river mouth in Shallow Bay, where the inferred surface temperatures exceeded 8°C.

Off the Yukon coast, a broad band of warmer temperatures was present just off the coast from Shingle Point to King Point. This band had a width of approximately 15 km, temperatures ranging from 5-6°C, and attenuance values of 2.4-3.9 m^{-1}. A narrow (2-3 km) band of cooler water was found adjacent to shore, inshore of the aforementioned band; inferred temperatures were 4-5°C.

To the west of Kay Point, the inshore boundary of the warmer water was considerably farther from shore and roughly followed the 20 m isobath, extending as far west as Herschel Island. Within the Herschel Island-Kay Point embayment, the surface waters were markedly cooler, with temperatures less than 2.3°C in the eastern half and 2.3-4°C in the western portion. Attenuance levels were also reduced to levels of 2.4 m^{-1} or less. A strong front, particularly in surface temperatures, extended northwest from Kay Point; over distances of approximately 2 km, temperature decreased from 5-6°C to less than 4°C, and in the areas immediately adjacent to Kay Point, to less than 2.5°C.

On **5 September 1986** (Fig. 33) clouds obscured the satellite image of the Yukon coast, but data were available over most of Mackenzie Bay. The intense plume didn't reach western Mackenzie Bay on either day. The spatial extent of the intense plume appeared to have changed little from 3 September. Within the intense plume, attenuance levels remained over 5.1 m^{-1}; the areal extent of surface temperatures exceeding 8°C had apparently increased from 3 to 5 September, now extending over more than half of the intense plume area. On 5 September, the strong turbidity front roughly coincided with the 6°C surface isotherm, as compared to alignment with the 5°C isotherm two days previously.

The diffuse plume extending northwest along the Yukon coast, continental shelf and slope was more prominent in the thermal imagery data of 5 September than on 3 September. Surface temperatures exceeding 5°C were present at distances up to 60 km from the coast, some 10 to 30 km farther offshore than on 3 September. This broad band (20-30 km width) of warmer temperatures also extended well to the northwest of Herschel Island, at least 50-60 km beyond its westernmost extent on 3 September. On 5 September, a local temperature maximum (5-6°C) within the warm diffuse plume was evident north of Herschel Island over the edge of the continental shelf at depths of 50-100 m. By contrast, the turbidity levels of the diffuse plume decreased, at least marginally, from 3 to 5 September. Turbidity levels decreased from levels of 2.4 to 3.2 m^{-1} on 3 September to <2.4 m^{-1} on 5 September.

By **6 September 1986** (Fig. 34), viewing conditions improved considerably from those of the previous day. The sharp turbidity front found along the seaward boundary of the intense plume had moved little in the area immediately north of the Yukon coastline. Farther north (latitude >69.5°N) in northeast Mackenzie Bay, the intense plume front had advanced about 10 km farther offshore. As on 5 September (but unlike 3 September) the gradients along that part of the front were much larger than those observed farther south, within 55 km of the Yukon coastline. The areal extent of the very warm surface temperatures (>8°C) continued to increase within the intense plume. On this date, the 8°C isotherm nearly coincided with the 5.1 m^{-1} attenuance contour, in sharp contrast to the satellite observations of 3 and 5 September.

Off the Yukon coast, beyond the intense plume, attenuance levels continued to be low, less than 2.4 m^{-1} (Fig. 34). However, a finer-scale analysis of the 6 September satellite imagery and an examination of airborne radiation thermometer data from that date both showed slightly elevated turbidity levels extending northwest near the shelf break well beyond Herschel Island (see Figs. 31, 32 in Fissel et al. 1987). As in earlier observations of the diffuse portion of the Mackenzie plume, surface water temperatures exceeding 5°C were observed along the edge of the Yukon shelf as far west as 139.5°W. Waters of greater surface temperatures (6-7°C) were embedded within this large area, at distances of 30-40 km north of the coast; these warm waters extended nearly to Herschel Island. An area of warmer water (6-7°C) also occurred closer to shore off Kay Point, extending 20 km each way from this point. Along the Yukon coast itself, two large areas of cooler surface temperatures had developed since 3 September. The largest of these areas occurred between Shingle and Kay Points, extending up to 18 km offshore, with surface temperatures <3°C, and surface salinities of 26-28 psu or more (as seen in the transect 1 and 2 CTD data, Fig. 30). Very intense gradients in surface temperature and salinity were observed 10-15 km from the coast on both transects 1 (sites 3 to 3A) and 2 (sites 8 to 8A). This strong front extended north from the coast just west of Shingle Point, and then veered westward to Kay Point. Reduced temperatures were also found in the southeast part of Herschel Basin.

The **8 September 1986** satellite data (Fig. 35) offered excellent areal coverage. Off the Yukon coast, and in Mackenzie Bay proper, the diffuse plume had been displaced eastward from its position of 6 September 1986. Waters having surface temperatures exceeding 5°C were largely confined to areas east of 138°W on 8 September, whereas two days earlier waters with these temperatures had occupied most of the area from 138°W west to Herschel Island and north to 70°N. This difference implies an eastward displacement of 30-40 km in this area. The warm core of diffuse plume water that had extended along the continental shelf edge and over the Mackenzie Trough on 3-6 September was no longer evident in the satellite data of 8 September. However, the CTD data of 7 September 1986 from transects 4 and 5 revealed a minimum in surface salinity extending northwest over the Mackenzie Trough (Figs. 30, 31).

Off the Yukon coast, cold Arctic water had largely replaced the diffuse plume. In Herschel Basin and to the north and west of Herschel Island, most of the area had low surface water temperatures of 2.3 to 3.9°C, with the exception of warmer waters (4-5°C) occurring as a narrow (width of 5-8 km) coastal band from Herschel Island to Kay Point. A large area of cold Arctic water was also present between Kay Point and Shingle Point. This area of cold water (2.3 to 3.0°C) had doubled in size since 5 and 6 September, when it was first observed. A tongue of relatively warm water (maximum temperature of 5-6°C) extended southward from the diffuse plume proper to Kay Point; this tongue separated the two areas of cold Arctic water occurring on either side of Kay Point. A similar but less extended feature was observed in the visible band data.

Summary of Surface Distributions and Their Response to Winds

From late August to early September 1986, surface waters in the study area consisted of three reasonably distinct water types. Intense plume water, representing warm, fresh water discharged from the Mackenzie River, was present around the Mackenzie Delta, between Shingle Point in the southwest and Kugmallit Bay in the east. This water type was generally confined to water depths <10 m. The spatial distribution of intense plume water exhibited modest changes during the study, particularly in southern Mackenzie Bay. Larger changes were observed in Kugmallit Bay and north of Richards Island, from 6 to 8 September. Southeasterly winds pushed the intense plume to the western side of Kugmallit Bay, and caused northward (offshore) advection from western Kugmallit Bay and north of Richards Island.

Diffuse plume water, situated adjacent to the intense plume, made up the surface layer over most of the Mackenzie Shelf. The diffuse plume extended over 100 km offshore to points near the shelf edge, in areas north of Richards Island. Farther to the east, past Kugmallit Bay, the diffuse plume was less dominant, occurring as an offshore band extending as far east as McKinley Bay.

Over the eastern portion of the Mackenzie Shelf, the surface layer consisted of cooler, more saline Arctic water. The influence of Arctic water was also observed in the form of cooler, more saline coastal waters off the Tuktoyaktuk Peninsula, from the shore to the 10-15 m isobath.

Diffuse plume waters also extended northwest from Mackenzie Bay, and were evident as much as 150 km beyond the intense plume. Off the Yukon coast, the diffuse plume exhibited considerable variability in location from Shingle to Kay Points. West of Kay Point, the diffuse plume generally was confined to areas along the outer shelf and beyond, over the axis of the Mackenzie Trough. Arctic water occurred at the surface in coastal areas west of Kay Point.

The diffuse plume waters clearly responded to shifts in wind patterns throughout the study area. The general distribution of water types encountered from late August to 3 September 1986 was consistent with preceding wind events. The strong northwest winds of 18 to 25 August would have caused the eastward orientation of the plume waters, while the weak to moderate easterly winds of 28 August to 3 September are consistent with offshore displacement of the plume water and the occurrence of cooler, more saline water between the plume and the coast. East of McKinley Bay, the surface waters were much more saline and generally cooler, particularly over the outer continental shelf. This cooler water was related to the close proximity of remnants of the pack ice, which were located comparatively close to the coast off the entrance to Amundsen Gulf in early September (Fig. 11A).

Throughout the study, winds were unusually low in strength; however, the weak to moderate wind events were reflected by corresponding changes in the distribution of the diffuse plume. From 3 to 6 September, weak westerly winds occurred at Tuktoyaktuk and at Herschel Island. Much stronger winds blew offshore (from the southwest) along the Yukon coast at Shingle and Kay Points, due to mountain baroclinicity. On 6 September the winds were very weak, followed by weak to moderate southeasterly to easterly winds on 7-8 September.

On the Mackenzie Shelf, changes in water mass distributions were consistent with the wind events of 6-8 September. On 6 September, the offshore extent of the diffuse plume had been reduced off the Tuktoyaktuk Peninsula. Also, two eastward oriented cores of warm water developed within the inshore region, in water depths of <10 m. Both features are consistent with eastward and inshore advection expected from westerly winds. By 8 September, changes in advection patterns were consistent with the general easterly wind regime of 7 to 8 September. Both the intense and diffuse plume waters off NE Mackenzie Bay and Kugmallit Bay were displaced offshore and westward.

Off the Yukon coast, the effect of the southwesterly winds of 3 to 6 September is strikingly evident in comparisons of surface layer distributions from 3 to 8 September, as observed from satellite imagery. Over this period, a pool of very cold and saline water expanded outward from the coast between Shingle and Kay Points, apparently in direct response to the wind forcing. This area was characterized by very intense frontal features, particularly along its eastern boundary. The growing area of cold water along the Yukon coast must have originated either vertically from below or laterally from the west along the coastline. Colder and more saline water was present west of Kay Point on both 3 and 6 September, but in both instances an intervening pool of warmer water was located off Kay Point itself. On the other hand, upwelling of the water from below is inconsistent with the large scale wind regime (generally westerly), which would favour downwelling rather than upwelling. Indeed, the vertical sections of water properties did not have the characteristics expected during large-scale coastal upwelling. However, upwelling may have been occurring in the upper 20 m of the water column. The source of the cold saline water may have been a combination of (1) shallow water upwelling driven by offshore (southwesterly) winds and (2) eastward advection.

In early September 1986, surface water property distributions appeared to respond to wind events of reduced magnitudes, and greater regional variability, than had been documented previously (cf. Cameron 1953; Herlinveaux and de Lange Boom 1975; Bradstreet and Fissel 1986; Fissel et al. 1987). The response of water properties to winds may have been limited to the surface layer and immediately below (depths <20 m), as there was little evidence of upwelling over the Mackenzie Shelf or near the Yukon coast in any of the vertical distributions of water properties (Figs. 17-28). While easterly wind events conducive to upwelling did occur within and preceding the observation period, wind speeds appear to have been too weak and of too limited duration to produce upwelling.

Frontal Features

Prominent surface fronts were visible in the satellite data. Their locations are mapped in Figure 36 for the band 1 (visible) and in Figure 37 for the band 4 (thermal) satellite data.

Visible Band Data.--The fronts observed from band 1 data, measured over the visible wavelengths, represented discontinuities in upper layer turbidity. The most prominent visible band fronts were associated with the seaward boundary of the intense Mackenzie River plume (Fig. 36). As observed in the satellite data, the front at the outer edge of the intense plume is characterized by a reduction in surface attenuance from >5 m^{-1} to <3.2 m^{-1} over a distance of 2 km or less. From 3 to 8 September 1986 the location of the intense plume front remained stationary in central Mackenzie Bay, about 30 km west of Richards Island near the 6 m isobath. Over a SW-NE distance of nearly 60 km, the position of the intense plume front varied by less than 6 km from 3 to 8 September 1986.

Within 20 km north of the Yukon coast between King and Shingle Points, the intense turbidity front exhibited greater variability. The intense plume front extended northeast from the coast near Shoalwater Bay. Farther west along the Yukon coast, the surface waters were clearer with reduced turbidities. Additional turbidity fronts separated moderately turbid from very clear water: (attenuance values changed from <2.4 m^{-1} to 3.2 m^{-1}) in this area. These fronts were reduced in length, typically 10 km or less, and had more random orientations (compare the east-west front on 3 September with the north-south front on 6 September--Fig. 36). Moreover, they exhibited considerable time variability on the three days with data from this area (3, 6 and 8 September).

The turbidity fronts off northeastern Mackenzie Bay also varied considerably from 5 to 8 September. (Clouds on 3 September limited data coverage in this area.) On 5 September, the plume front was situated some 30 km north of the coast of NE Mackenzie Bay, between the 6 and 8 m isobath, over a lateral distance of 70 km. On the following day, the intense plume was some 8 km farther north near the 10 m isobath. Immediately to the east of Hooper Island, the intense front moved shoreward to the area of North Head. Surface turbidities were moderate with no large gradients from the coastline out to just beyond the 10 m isobath, where there was a less intense front separating waters of <2.4 and >3.2 m^{-1} in attenuance. By 8 September, the intense plume front off NE Mackenzie Bay was not prominent. The surface turbidities decreased fairly uniformly over distances of 20-25 km, from >5.1 m^{-1} attenuance at the 10 m isobath to <2.4 m^{-1} at 70°N (water depths of approximately 30 m).

To the east of Richards Island through Kugmallit Bay, a front delineating the limits of the intense plume also exhibited considerable daily displacements. On 5 September, the intense plume front was oriented approximately NW to SE across Kugmallit Bay, passing just seaward of Hendrikson Island to a coastal point south of Tuktoyaktuk Harbour. On the following day, 6 September, the intense plume front in Kugmallit Bay was oriented north-south approximately 5 km from the eastern shore. The front also occurred as a distinct east-west feature, across Kugmallit Bay, with a shoreward retreat to the coastline of Hendrikson Island in the middle of the Bay. By 8 September, the front had again relocated. The intense north-south front was now some 9 km west of its location of two days previously, approximately midway across Kugmallit Bay.

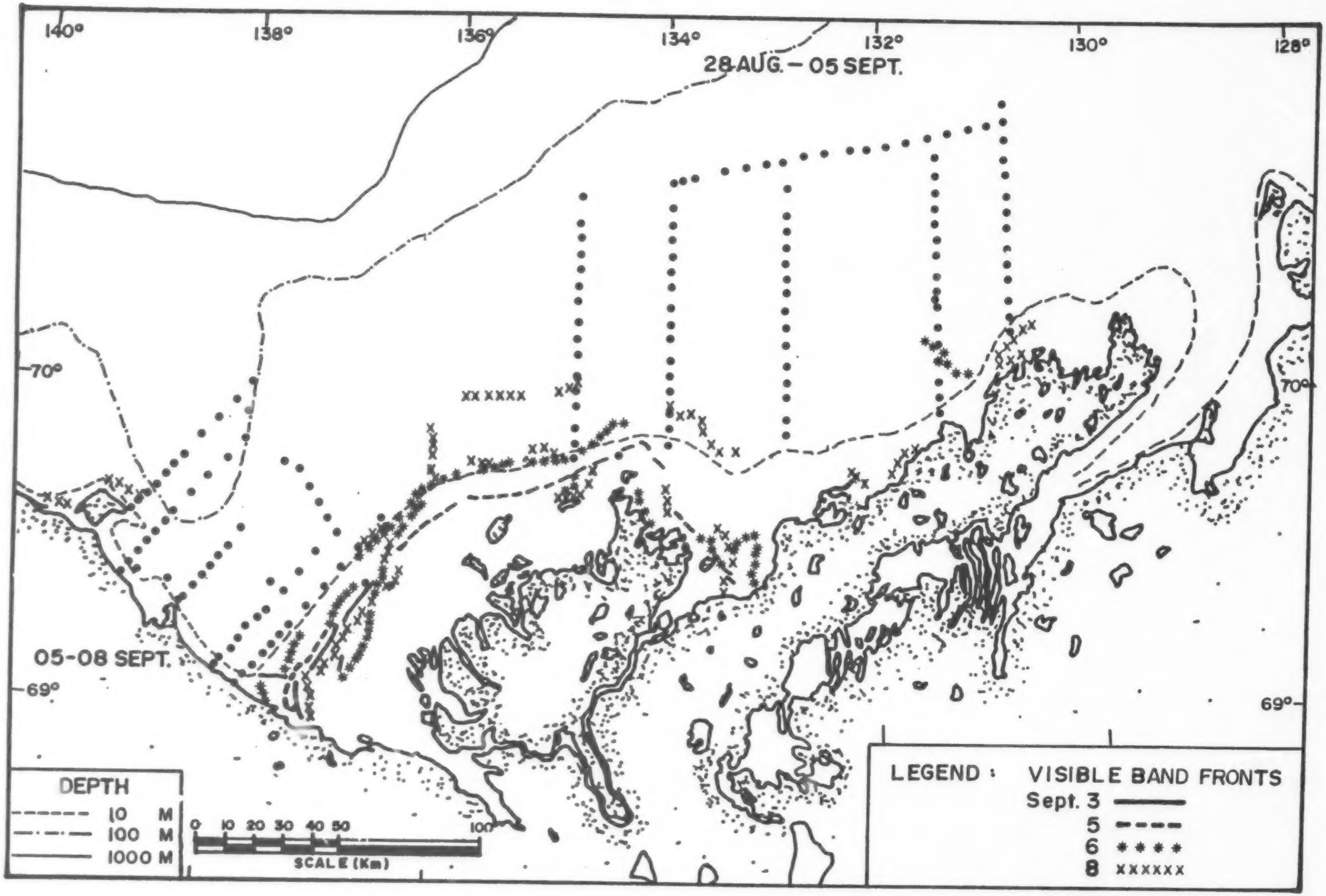

140°
138°
136°
134°
132°
130°
128°
28 AUG. – 05 SEPT.
05-08 SEPT.
70°
69°
70°
69°
DEPTH
10 M
100 M
1000 M
0 10 20 30 40 50 100
SCALE (Km)
LEGEND : VISIBLE BAND FRONTS
Sept. 3
5
6 ****
8 xxxxxx
xx xxxx

Figure 36. Locations of fronts, as inferred from band 1 (visible) satellite data of 3, 5, 6 and 8 September 1986. Frontal features were identified as changes of two colour ranges or more (Figs. 32 to 35) over distances of less than 3 km.

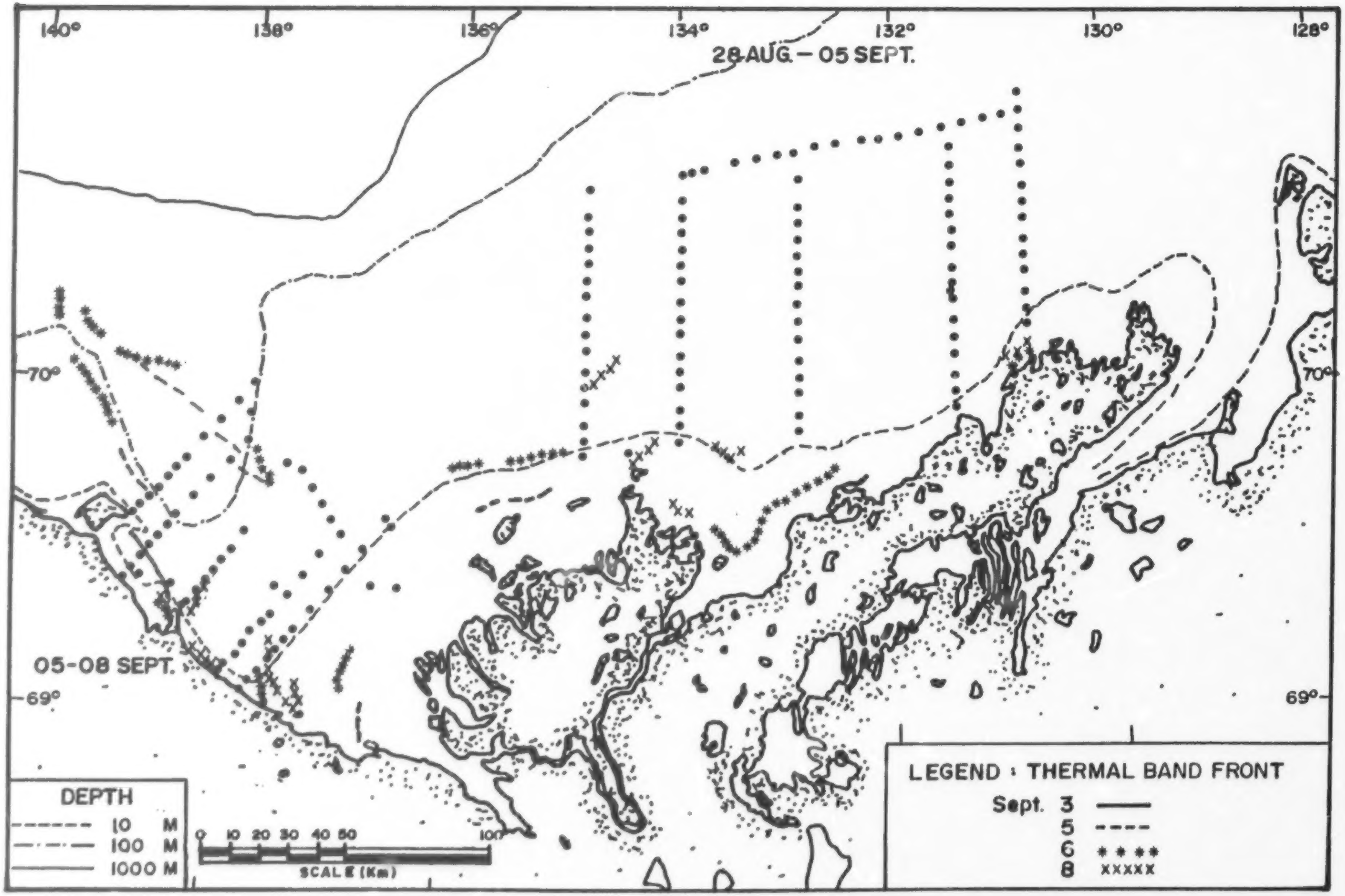

140°
138°
136°
134°
132°
130°
128°
28 AUG. – 05 SEPT.
05-08 SEPT.
70°
69°
DEPTH
10 M
100 M
1000 M
0 10 20 30 40 50 100
SCALE (Km)
LEGEND : THERMAL BAND FRONT
Sept. 3
5
6 ****
8 xxxxx

Figure 37. Locations of fronts, as inferred from band 4 (thermal) satellite data of 3, 5, 6 and 8 September 1986. Frontal features were identified as changes of two colour ranges or more (Figs. 32 to 35) over distances less than 3 km.

Away from the intense Mackenzie plume, frontal features were rarely observed in the visible band data. This was partly due to the lack of satellite sensitivity to small variations in surface turbidity. Contributing factors included the sharp reduction in turbidity levels caused by settling of particulates from the surface layer, and the lower level of active resuspension of particulates from the bottom in waters exceeding 10-15 m deep (Fissel and Birch 1984). In the satellite data of this study, the only consistently distinguishable turbidity fronts identified away from the Mackenzie Delta occurred on 8 September. They were associated with (1) coastal bands of moderately turbid water along the north coast of Herschel Island, and (2) turbid bands located along the coast of the Tuktoyaktuk Peninsula. In the latter case, the turbid water (attenuance of 3.2 to 4.5 m^{-1}) and associated front were located as much as 30 km offshore, over the shallow waters (<10 m depth) off the eastern end of the Tuktoyaktuk Peninsula (Fig. 36). An extended front associated with the large area of highly turbid water well off McKinley Bay on 6 September 1986 was of questionable validity.

Thermal Band Data.--Thermal fronts were identifiable more frequently beyond the intense Mackenzie plume (Fig. 37). This difference was due to the greater sensitivity of the infrared satellite sensor in detecting variations associated with the diffuse plume. However, the intense plume appeared to be better delineated by turbidity fronts rather than temperature fronts. In only two instances did visible and thermal fronts coincide at the edge of the intense plume (north of NE Mackenzie Bay on 5 September, and in Kugmallit Bay on 6 September). In most instances, particularly in western Mackenzie Bay, the surface temperatures exhibited more gradual changes across the edge of the intense plume as defined by turbidity. The visible frontal boundary was usually found at temperatures ranging from 5 to 7°C, although on the two occasions of good agreement between locations of thermal and turbidity fronts, the surface temperatures inside the intense plume exceeded 8°C.

Thermal fronts were most commonly observed (1) within 20 km of the Yukon coast between Shingle Point and Herschel Island; and (2) near Herschel Canyon at and beyond the continental shelf edge (Fig. 37). In both areas the fronts generally occurred as sharp thermal gradients between very cold Arctic water

(<4°C and usually <2.3°C) and warmer water having diffuse Mackenzie plume characteristics (>5°C).

Off the Yukon coast, intense thermal fronts occurred between Kay Point and Herschel Island on 3 September. The gradients were particularly intense within 5 km west of Kay Point and off the east tip of Herschel Island. On 6 September, a thermal front remained just west of Kay Point, and another front, extending approximately 12 km offshore, occurred midway between Shingle and Kay Points. By 8 September 1986 this latter front had been displaced east by 5-10 km towards Shingle Point, and became elongated with a NW-SE orientation, extending over a distance of 25-30 km. Other notable thermal fronts were situated within 5 km of the coast immediately west of King Point and extending northwards and offshore from Kay Point to a distance of 12-15 km. Similar frontal features had been observed off the Yukon coast from 20 to 28 August in 1985 (Bradstreet and Fissel 1986).

In the Herschel Canyon area, thermal fronts were present on 5 and 6 September 1986, associated with the two sides of the diffuse plume that extended northwest past Herschel Island. The landward front occurred over water depths between 50 and 100 m, while the seaward front was 15 to 30 km farther offshore. Thermal fronts extended as far east as 138°W on the seaward edge of the diffuse plume on both dates.

Over the Mackenzie Shelf, the largest thermal gradients appeared to occur over the outer half of the continental shelf. Measurable temperature and salinity fronts were evident in the ship-based CTD observations of 29 August to 3 September (Fig. 30). Identifiable thermal fronts observed in the satellite data were limited to the inner half of the shelf. North of Richards Island, thermal fronts of 10 km length occurred over the mid-shelf on 6 September (approximately 100 km offshore) and on 8 September (approximately 70 km offshore). The fronts separated waters of temperature >5°C from <4°C and >7°C from <6°C, respectively. On 8 September, a warm thermal front was also observed due north of Kugmallit Bay at the 10 m isobath. Farther east, thermal fronts occurred off the Tuktoyaktuk Peninsula, immediately east of McKinley Bay, on 6 and 8 September. On 6 September, the front separated a narrow band of moderately warm water (>5°C) from cold Arctic water (<4°C).

Two days later, in the same area, the horizontal gradient was unchanged with the coastal band having temperatures >7°C and the offshore water with temperatures of <6°C.

A more detailed examination of the spatial scales of thermal fronts was carried out using the ship-based continuous near-surface temperature data. Four fronts representing the largest temperature changes observed in each region are plotted in Figure 38. For the thermal front bordering the intense plume on 8 September, the greatest temperature change (1 C°) occurred over a distance of 2 km, between stations 202 and 203. This front was also crossed, obliquely, between stations 201 and 202; the oblique crossing accounts for the seemingly slower change in temperature (Fig. 38).

Two thermal fronts 10 to 15 km off the Yukon coast, on transects 1 and 2, had much larger horizontal gradients. For the thermal front between stations 3 and 3a on 5 September, a temperature change of 1.7 C° occurred over a distance of 800 m. On transect 2, between sites 8 and 8A, an even larger temperature change of 3.6 C° occurred over a distance of 1.2 km on 6 September.

Thermal fronts over the broad expanse of the Mackenzie shelf appeared to be less intense than those off the Yukon coast. One of the largest amplitude thermal fronts was observed on 31 August between sites 64A and 64B on transect 8. Although the change in temperature was considerable, approximately 1 C°, the increase was spread over 5 km. A considerable amount of small scale variability was also evident, with temperature amplitudes of 0.1-0.3 C°, and spatial scales ranging upward from approximately 100 m. The resulting thermal gradient was approximately one order of magnitude shallower than the intense frontal features measured off the Yukon coast. While thermal gradients over the Mackenzie shelf are much smaller than those off the Yukon coast, the magnitude of salinity gradients may be more comparable. The distribution of surface properties (Fig. 30) reveals more structure in salinity than temperature on the Mackenzie shelf.

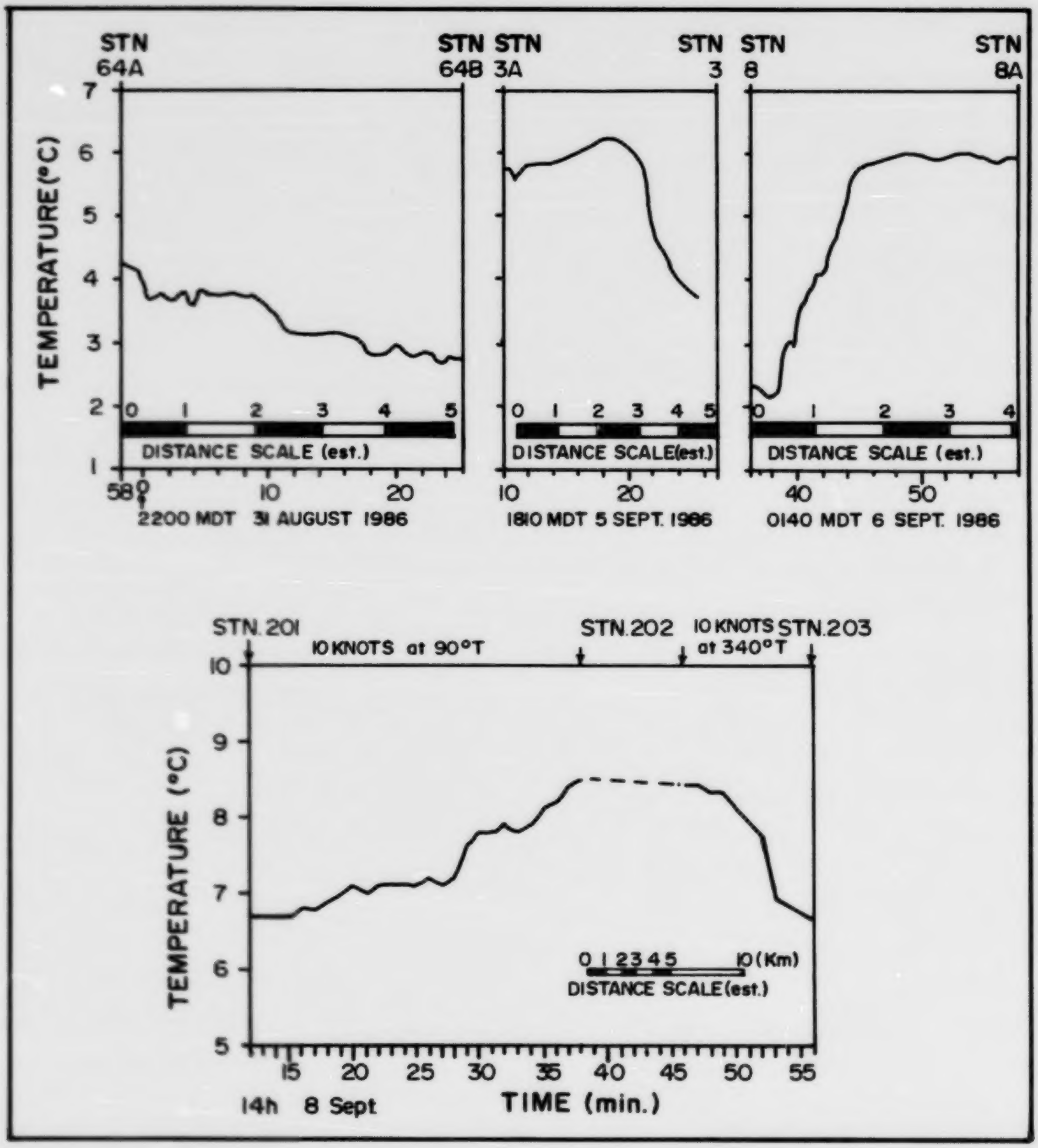


Figure 38. Continuous near-surface temperature data, collected from the M.V. Arctic Ivik, across strong thermal fronts.

NET SAMPLING OF ZOOPLANKTON

During this study 202 zooplankton samples were taken. Of these, 97 samples were identified to species level and the remaining 105 to major taxonomic group (copepod, euphausiid, etc.).

	Oblique Tows	Horizontal Tows At Surface	Horizontal Tows At Depth	Total
No. Identified to Group	46	52	104	202
No. Identified to Species	46	18	33	97

Most horizontal and surface samples that were identified to species were taken near feeding whales and, as such, are not representative of the species composition of the plankton of the entire study area.

Station locations are shown in Figure 6 and details for each sample are shown in Appendix 4. Appendix 5 gives the biomasses of major groups of plankton in each tow.

Samples were categorized by geographic location and water mass characteristics. The three geographic areas sampled were (1) off the Yukon coast, (2) in the industrialized zone off Richards Island, and (3) off the eastern Tuktoyaktuk Peninsula (Fig. 6). Three water masses were present in the study area. These were Arctic water, intense Mackenzie River plume water, and diffuse Mackenzie River plume water (see "Water Mass Analysis"). In addition, there were combinations of intense/diffuse plume water and diffuse plume/arctic water. Horizontal tows at the surface and at depth usually sampled a specific water mass but may have been contaminated on the way up and down by plankton from another water mass. Horizontal tows provide specific information about the zooplankton in specific water masses. Oblique tow data were used mainly to characterize and compare the average biomass and composition of zooplankton from different areas.

Geographic Distribution of Zooplankton

Forty-six oblique tows were made during the study. In waters over 50 m deep the tows sampled the upper 50 m; in shallower water the tows were made to within 2 to 4 m of the bottom. Mean biomass in all oblique tows was 172 mg/m^3 (Table 3). Copepods dominated the biomass in oblique tows and accounted for 65% of total biomass. The three dominant species in the tows were all copepods, with Calanus hyperboreus being the most important species in terms of biomass (Table 3). The eleven zooplankton species that each accounted for more than one percent of total zooplankton biomass together comprised 87% of total zooplankton biomass.

Overall, there were some differences in the distribution of total zooplankton biomass (as documented by oblique tows) among the three geographic areas that were sampled (Tables 4 and 5). The significance of these differences in biomass was assessed with analysis of variance, based on log transformed data (Table 4). Griffiths et al. (1987) showed that, in the Beaufort Sea, zooplankton biomass decreased with increasing water depth, so the samples were further assigned to a depth category in a two-way (area, depth) analysis. Forty metres was chosen as the boundary between the two depth ranges. In three of the analyses there was a significant area by depth interaction term (Table 4). In these cases, differences between areas were inconsistent between depths. For example, total zooplankton biomasses off the Yukon coast and off the Tuktoyaktuk Peninsula were higher in shallow water than in deeper water, whereas in the industrialized zone, total biomass was higher in deep water than in shallow water (Table 4). A significant interaction term precludes interpretation of the remainder of the analysis, so, for these three groups, biomass in different areas was assessed separately for each depth range.

Table 3. Mean biomass (mg/m^3 wet weight) of major groups and species of zooplankton in 46 oblique tows taken in the Southeastern Beaufort Sea in August and September 1986. Also shown is the percent of mean total zooplankton biomass represented by each of the indicated taxa. The major species were those that accounted for at least 1% of total biomass.

Major Taxa	Biomass mg/m^3	Percent of Total Biomass	Major Species	Biomass mg/m^3	Percent of Total Biomass
Hydrozoa	16.5	9.6	*Aglantha digitale*	10.7	6.2
Ctenophora	7.2	4.2	*Mertensia ovum*	5.8	3.4
Pteropoda	2.0	1.2	*Spiratella helicina*	1.9	1.1
Chaetognatha	7.5	4.4	*Sagitta elegans*	6.7	3.9
Pisces	8.8	5.1	Gadidae YOY	5.8	3.4
Mysidacea	6.3	3.6	*Mysis litoralis*	5.6	3.3
Euphausiacea	4.6	2.7	*Thysanoessa raschii*	3.3	1.9
Decapoda	0.7	0.4			
Copepoda	112.4	65.4	*Limnocalanus macrurus*	22.0	12.8
			Calanus hyperboreus	63.6	37.0
			Calanus glacialis	22.7	13.2
Hyperiidea	2.2	1.3	*Parathemisto libellula*	1.7	1.0
Gammaridea	0.5	0.3			
Other Taxa	3.3	1.9			
All Zooplankton	171.9	100.0			

Table 4. Analyses of variance in the biomass (log transformed) of major taxa over two depth ranges and in two areas in the Southeastern Beaufort Sea in August and September 1986. When the depth by area interaction term was significant, one-way comparisons of areas were done for each depth range separately. Significance levels are shown by asterisks (* $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$).

	Mean Zooplankton Biomass (mg/m^3)								
	Yukon Coast Depth Range (m)		Industrialized Zone Depth Range (m)		Tuktoyaktuk Peninsula Depth Range (m)		Analysis of Variance (F)		
	<40	≥40	<40	≥40	<40	≥40	Area	Depth	Area x Depth
2 Way ANOVA (Area, Depth)									
Hydrozoa	15.7	12.1	19.3	15.3	20.6	11.0	0.96 ns	1.31 ns	0.38 ns
Ctenophora	3.7	3.9	6.8	4.0	16.5	14.5	4.11 *	1.44 ns	0.34 ns
Pteropoda	1.3	0.9	2.5	2.3	3.0	2.1	1.68 ns	0.00 ns	0.11 ns
Chaetognatha	9.4	2.3	5.4	3.7	19.8	3.1	0.21 ns	4.15 *	1.00 ns
Pisces	3.5	0.9	15.7	4.5	18.6	3.0	9.05 ***	16.50 ***	0.82 ns
Mysidacea	14.5	0.0	12.4	0.1	6.0	0.5	0.48 ns	22.77 ***	1.20 ns
Euphausiacea	21.7	1.8	3.4	0.7	0.0	0.0	5.68 ns	4.42 *	1.43 ns
Decapoda	1.0	0.4	0.6	0.4	1.3	0.2	0.57 ns	4.10 *	0.26 ns
Copepoda	187.3	63.6	61.2	141.3	117.8	159.9	-[a]	-	4.31 *
Hyperiidea	5.4	2.5	0.8	2.5	1.0	1.1	-	-	5.61 **
Gammaridea	1.0	0.4	0.6	0.3	0.3	0.2	1.81 ns	1.57 ns	0.45 ns
Other Taxa	2.1	2.5	3.0	1.6	7.4	3.5	-	-	-
All Zooplankton	266.5	91.4	131.6	176.6	212.3	199.0	-	-	3.67 *
Sample size (df)	7	8	11	10	8	2	(2,40)	(1,40)	(2,40)
1 Way ANOVA (Area)									
Depth ≤40 m									
Copepoda	187.3		61.2		117.8		1.70 ns	df = 2,23	
Hyperiidea	5.4		0.8		1.0		12.01 ns	df = 2,23	
All Zooplankton	266.5		131.6		212.3		1.08 ns	df = 2,23	
Depth >40 m									
Copepoda		63.6		141.3		159.9	4.15 *	df = 2,17	
Hyperiidea		2.5		2.5		1.1	0.46 ns	df = 2,17	
All Zooplankton		91.4		176.6		199.0	3.58 *	df = 2,17	

[a] Significant interaction term precluded interpretation of depth and area differences; see one-way analyses.

Table 5. Mean biomass of major taxa and dominant species of zooplankton in oblique tows taken in three areas and two depth ranges in the Southeastern Beaufort Sea in August and September 1986. The percent of mean total zooplankton biomass represented by each taxon and species is also shown.

	Yukon Coast Depth Range (m)				Industrialized Zone Depth Range (m)				Tuktoyaktuk Pen. Depth Range (m)			
	<40		>39		<40		>39		<40		>39	
Taxon	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%
All Zooplankton	266.5		91.4		131.6		176.6		212.3		199.0	
Hydrozoa	15.7	5.9	12.1	13.3	19.3	14.7	15.3	8.7	20.6	9.7	11.0	5.5
Halitholus cirratus	1.2	0.5	0.4	0.5	3.7	2.8	1.7	1.0	4.9	2.3	1.9	0.9
Aglantha digitale	11.6	4.4	9.4	10.3	11.2	8.5	9.1	5.1	13.6	6.4	6.0	3.0
Aeginopsis laurentii	0.8	0.3	0.7	0.8	1.9	1.4	2.9	1.6	1.4	0.7	2.3	1.2
Ctenophora	3.7	1.4	3.9	4.3	6.8	5.1	4.0	2.3	16.5	7.8	14.5	7.3
Mertensia ovum	1.4	0.5	3.7	4.0	4.9	3.8	3.4	1.9	14.8	7.0	9.6	4.8
Pteropoda	1.3	0.5	0.9	1.0	2.5	1.9	2.3	1.3	3.0	1.4	2.1	1.1
Spiratella helicina	1.3	0.5	0.8	0.9	2.3	1.8	1.9	1.1	3.0	1.4	2.1	1.0
Chaetognatha	9.4	3.5	2.3	2.5	5.4	4.1	3.7	2.1	19.8	9.3	3.1	1.5
Sagitta elegans	8.8	3.3	1.5	1.6	5.0	3.8	1.9	1.1	19.4	9.1	2.6	1.3
Pisces	3.5	1.3	0.9	1.0	15.7	11.9	4.5	2.5	18.6	8.8	3.0	1.5
Gadidae YOY	1.2	0.5	0.7	0.8	10.5	8.0	2.8	1.6	13.0	6.1	3.0	1.5
Mysidacea	14.5	5.4	0.0	0.0	12.4	9.4	0.1	0.1	6.0	2.8	0.5	0.2
Mysis litoralis	14.5	5.4	0.0	0.0	11.4	8.7	0.1	0.0	4.0	1.9	0.5	0.2
Euphausiacea	21.7	8.2	1.8	2.0	3.4	2.5	0.7	0.4	0.0	0.0	0.0	0.0
Thysanoessa inermis	3.0	1.1	0.5	0.6	0.2	0.1	0.4	0.2	0.0	0.0	0.0	0.0
Thysanoessa inermis A	3.3	1.2	0.6	0.7	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Thysanoessa raschii	15.4	5.8	0.5	0.6	3.2	2.4	0.3	0.2	0.0	0.0	0.0	0.0
Copepoda	187.3	70.3	63.6	69.6	61.2	46.5	141.3	80.0	117.8	55.5	159.9	80.4
Limnocalanus macrurus	134.4	50.4	7.4	8.1	0.8	0.6	0.0	0.0	0.1	0.0	0.0	0.0
Calanus hyperboreus	18.7	7.0	34.5	37.7	39.7	30.2	111.4	63.1	90.2	42.5	122.5	61.6
Calanus glacialis	27.7	10.4	18.3	20.1	18.5	14.1	24.4	13.8	22.8	10.7	36.1	18.1
Pseudocalanus minutus	2.9	1.1	0.2	0.2	0.6	0.5	0.3	0.1	2.2	1.0	0.8	0.4
Euchaeta glacialis	0.2	0.1	2.5	2.7	0.8	0.6	3.8	2.1	0.6	0.3	0.0	0.0
Metridia longa	2.2	0.8	0.5	0.6	0.2	0.1	0.9	0.5	0.8	0.4	0.4	0.2
Hyperiidea	5.4	2.0	2.5	2.8	0.8	0.6	2.5	1.4	1.0	0.5	1.1	0.5
Parathemisto libellula	4.2	1.6	2.0	2.2	0.5	0.4	2.2	1.2	0.6	0.3	0.5	0.3
Sample size	7		8		11		10		8		2	

Total Biomass of All Zooplankton

In waters <40 m deep there was no statistically significant difference in total zooplankton biomass in oblique tows taken in the three areas (0.1>p>0.05), although the mean values were higher off the Yukon and Tuktoyaktuk Peninsula than in the industrialized zone (Table 4). The difference in mean biomasses in the three areas was mainly attributable to the abundance of the small copepod *Limnocalanus macrurus*, in shallow waters off the Yukon (see below), and the abundances of *Calanus* sp. off the Tuktoyaktuk Peninsula. In water depths ≥40 m, biomass of all zooplankton was significantly higher in the industrialized zone and off the Tuktoyaktuk Peninsula than off the Yukon coast.

Copepods

In water depths <40 m, biomass of copepods was not significantly different among the three areas (0.1>p>0.05). In deeper water, copepod biomass was significantly higher in the industrialized zone and off the Tuktoyaktuk Peninsula than off the Yukon coast. *Calanus hyperboreus*, *C. glacialis*, and *Limnocalanus macrurus* together accounted for 63% of the biomass of all zooplankton and 96% of the biomass of all copepods in oblique tows.

Limnocalanus macrurus was the dominant species in shallow water off the Yukon coast where it accounted for 50% of total zooplankton biomass (Table 5). It was uncommon in deeper water off the Yukon coast, rare in shallow water in the industrialized zone and off the eastern Tuktoyaktuk Peninsula, and apparently absent in deep water east of the Yukon coast. It accounted for 39% of total zooplankton biomass in all samples taken off the Yukon coast. In 1985 it accounted for 68% of total zooplankton biomass taken in the same area. In the eastern Alaskan Beaufort Sea, it was the dominant copepod in nearshore waters, but because the extent of the nearshore water mass varied from year to year, the importance of *L. macrurus* to the whole study area also varied (Griffiths et al. 1987). A similar phenomenon may have occurred in our study area (see Discussion).

Calanus hyperboreus was the dominant species in deeper water off the Yukon coast and in both deep and shallow water off the Tuktoyaktuk Peninsula and in the industrialized zone (Table 5). *Calanus glacialis* was the second most abundant copepod in these depth/area combinations (Table 5). In all but nearshore waters, these two species are generally the dominant zooplankters in the Beaufort Sea (Grainger 1965; Griffiths and Buchanan 1982; Griffiths et al. 1987).

Other Crustaceans

Both mysids and euphausiids were significantly more abundant in samples taken in water depths <40 m than in deeper water. Mysids were equally abundant in the three areas (Table 4). Biomass of amphipods differed among the three areas and appeared to decrease from east to west. *Mysis litoralis*, a species typical of shallow nearshore waters, was the dominant mysid; *Thysanoessa raschii* was the most abundant euphausiid (Table 5).

Hyperiid amphipods were equally abundant in the three areas (Table 4). *Parathemisto libellula* was the dominant amphipod collected.

Gelatinous Zooplankton

There was no significant difference in biomass of hydrozoans and chaetognaths among areas (Table 4). Biomass of ctenophores was much higher off the Tuktoyaktuk Peninsula than in the other two areas; biomass of ctenophores appeared to increase from west to east (Table 4).

Aglantha digitale was the dominant hydrozoan in all depths and areas (Table 5). *Sagitta elegans* was the dominant chaetognath and *Mertensia ovum* was the dominant ctenophore.

Fish Larvae

Fish larvae, mainly young-of-the-year cod (probably *Boreogadus saida*), were more abundant in shallow than deep water, and at both depths were more abundant in the industrialized zone and off the Tuktoyaktuk Peninsula than off the Yukon coast (Tables 4, 5).

The regional differences in dominant species noted above are within the range of variation for typical Arctic zooplankton communities. The overall species composition of the plankton collected during this study was typical of that found previously in the Beaufort Sea (Grainger 1965; Griffiths and Buchanan 1982; Bradstreet and Fissel 1986; Griffiths et al. 1987). In the following sections we attempt to identify some of the physical variables that could affect the distribution and standing crop of zooplankton and describe the biomass and species composition of zooplankton associated with bowhead whales.

Distribution of Zooplankton in Relation to Physical Oceanography

We made 52 horizontal tows at the surface and 104 horizontal tows below the surface. Physical oceanographic measurements made at each station allowed us to define the physical characteristics of the water associated with each tow and thus to typify water masses in terms of the kinds and quantities of zooplankton present. These data were also used to determine some of the physical factors associated with concentrations of zooplankton.

In most cases, the echosounder results were used to select the tow depth. Some tows were made in layers of concentrated zooplankton that were evident on the echosounder and some tows were made outside of concentrations. Mean biomass within layers that were evident on the echosounder was 2.6 times higher than mean biomass in tows made outside of layers. The echosounder was not functional during 33 of the tows. Mean biomass in tows made within known layers was similar to mean biomass in tows made when the echosounder was not functioning.

	Outside Layers		Within Layers		No Echosounder	
	mg/m^3	± s.d	mg/m^3	± s.d	mg/m^3	± s.d
All Zooplankton	74	61	189	284	148	368
Copepods	39	44	111	258	119	368
Sample Size	23		48		33	

Distribution of Zooplankton and Water Masses

Three major water masses were identified in the study area (see "Water Mass Analysis"). Intense plume water had high temperature and turbidity, a salinity of 10-18 psu, and was found immediately adjacent to the Mackenzie River Delta. Diffuse plume water was generally colder than intense plume water and had a salinity of 12 to 26 psu. Due to the nature of the winds, diffuse plume water was found to distances of 100 km or more offshore and was the most common surface water mass in the study area. Arctic water had a salinity >28 psu or a temperature less than -1.5°C at any salinity. Arctic water was found below the surface water mass throughout the study area, and was occasionally present at the surface (Fig. 22). Two intermediate water masses were also identified. They represented a mixture of intense and diffuse plume water, or of diffuse plume and Arctic water. Intense/diffuse water was not associated with any of our samples. In most cases, diffuse/Arctic water was found at depths intermediate between surface diffuse plume water and the Arctic water below it.

Biomass in surface tows was highest where Arctic water was found at the surface (Table 6). In places where Mackenzie plume water was at the surface, biomass was extremely low (Table 6). Overall, mean biomass was eight times higher in Arctic surface water than in surface water that had any Mackenzie River influence. The main difference in taxonomic composition of surface zooplankton among the water mass types was in the biomass of copepods (Table 6). Biomass of copepods increased as the influence of Mackenzie River water decreased.

Below the surface, mean biomass was also highest in Arctic water, very low in diffuse plume waters, and intermediate in water that was a mixture of diffuse plume and Arctic water (Table 7). Most of the difference was due to differences in biomass of copepods:

Table 6. Mean biomass (mg/m^3) of major groups in surface tows taken at stations with different water mass characteristics. Also shown is the percent of mean total zooplankton biomass represented by each taxon. Surface tows taken near a turbidity front (stations 201, 202, 203) are not included.

	Intense Plume			Diffuse Plume			Diffuse/Arctic			Arctic Water		
Taxon	Mean ± s.d.		%	Mean ± s.d.		%	Mean ± s.d.		%	Mean ± s.d.		%
Hydrozoa	0.1	0.0	1.4	3.2	11.2	36.8	3.0	3.3	24.7	1.5	1.2	2.1
Ctenophora	0.1	0.0	1.1	2.9	7.3	34.2	0.6	0.9	5.2	0.5	0.7	0.7
Pteropoda	0.0	0.0	0.5	0.3	1.3	3.5	0.0	0.1	0.3	1.0	2.1	1.4
Chaetognatha	0.5	0.0	7.3	0.1	0.4	1.4	0.0	0.1	0.2	0.1	0.2	0.1
Pisces	0.0	0.0	0.0	0.5	1.9	6.3	0.0	0.0	0.0	0.0	0.0	0.0
Mysidacea	4.9	0.0	75.5	0.0	0.1	0.3	0.4	0.9	3.1	0.0	0.1	0.1
Euphausiacea	0.0	0.0	0.0	0.1	0.7	1.7	0.0	0.0	0.0	0.0	0.1	0.1
Decapoda	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Copepoda	0.9	0.0	14.3	0.9	1.4	10.5	7.6	16.7	63.5	69.2	150.7	95.1
Hyperiidea	0.0	0.0	0.0	0.1	0.4	1.4	0.0	0.0	0.1	0.1	0.2	0.2
Gammaridea	0.0	0.0	0.2	0.1	0.2	0.7	0.1	0.1	0.4	0.1	0.1	0.1
Other Taxa	0.0	0.0	0.0	0.3	0.7	3.2	0.3	0.7	2.4	0.1	0.1	0.1
All Zooplankton	6.4	0.0	100.0	8.6	16.4	100.0	12.0	17.2	100.0	72.8	153.6	100.0

	Diffuse Plume	Diffuse/Arctic	Arctic Water
Copepods (mg/m^3)	4.8	62.3	144.2
All other Taxa (mg/m^3)	24.4	44.6	65.9
Total (mg/m^3)	29.2	106.9	210.1

The mean biomass of all other taxa was similar in Arctic and diffuse/Arctic water, although higher than their mean biomass in diffuse plume water.

Mean biomass of zooplankton in oblique tows also was highest where Arctic water was found at the surface and decreased with increasing Mackenzie River water influence at the surface (Table 8). Again, most of the difference in biomass among water masses was due to differences in biomass of copepods. Differences in biomass of zooplankton among water mass types were not as great in oblique tows as in surface tows or horizontal tows below the surface (Tables 6, 7, 8). This is not surprising, given that a single oblique tow can sample a variety of water masses at different depths. The net effect of Mackenzie River water at the surface was to reduce the total biomass found in the upper water layers. However, biomass in oblique tows taken in areas where there was some diffuse or intense plume water at the surface appears to have been similar regardless of the depth to which the oblique tow was taken:

Water Type at Sfc: Max. Sample Depth:	Mackenzie <25 m	Mackenzie >24 m	Arctic Water All
Mean Total Biomass mg/m^3 ± s.d. (n)	139 ± 98 (17)	168 ± 107 (23)	326 ± 279 (5)

Most horizontal tows that were identified to species were taken near feeding whales. These samples are not representative of the study area as a whole. *Limnocalanus macrurus* is over-represented and *Calanus hyperboreus* and *C. glacialis* are under-represented in these samples (compare Tables 9 and 3).

Table 7. Mean biomass (mg/m^3) of major groups as a function of water mass characteristics in all horizontal tows at depth and in tows taken within layers evident on the echosounder output. Also shown is the percent of mean total zooplankton biomass represented by each taxon.

	Diffuse Plume			Diffuse/Arctic			Arctic Water		
Taxon	Mean ± s.d.		%	Mean ± s.d.		%	Mean ± s.d.		%
All Tows (Sample size)		23			20			61	
Hydrozoa	6.0	5.6	20.5	17.3	22.4	16.2	17.6	19.4	8.4
Ctenophora	3.7	4.7	12.6	4.3	7.4	4.0	5.6	9.8	2.7
Pteropoda	2.4	3.6	8.3	3.9	6.1	3.7	3.5	8.0	1.7
Chaetognatha	0.3	0.7	1.1	2.2	3.6	2.1	5.2	10.9	2.5
Pisces	4.7	9.6	16.1	5.4	7.4	5.0	8.5	17.0	4.1
Mysidacea	4.5	15.2	15.5	3.4	10.2	3.1	12.4	29.0	5.9
Euphausiacea	0.3	1.0	1.0	1.6	4.0	1.5	5.8	14.7	2.8
Decapoda	0.4	0.7	1.3	1.3	1.6	1.2	1.0	1.5	0.5
Copepoda	4.8	12.6	16.5	62.3	145.5	58.3	144.2	337.6	68.6
Hyperiidea	0.8	1.7	2.8	2.2	3.7	2.0	3.1	3.0	1.5
Gammaridea	0.1	0.3	0.4	0.3	0.4	0.3	0.7	1.0	0.3
Other Taxa	1.2	0.9	4.0	2.7	3.5	2.5	2.5	2.6	1.2
All Zooplankton	29.2	39.2	100.0	106.9	141.4	100.0	210.1	351.4	100.0
Within Layers (Sample Size)		3			11			34	
Hydrozoa	4.8	3.6	13.5	24.8	25.3	23.8	20.6	22.8	9.0
Ctenophora	6.8	10.1	19.4	6.5	9.3	6.2	6.3	9.8	2.7
Pteropoda	3.9	4.1	11.2	4.7	7.3	4.5	4.4	10.5	1.9
Chaetognatha	0.2	0.2	0.6	3.0	3.3	2.8	7.1	13.7	3.1
Pisces	4.7	5.3	13.2	7.1	8.9	6.8	11.7	22.0	5.1
Mysidacea	0.0	0.0	0.0	2.0	3.9	2.0	21.0	36.7	9.2
Euphausiacea	1.4	2.5	4.1	2.9	5.2	2.8	8.9	19.0	3.9
Decapoda	0.1	0.3	0.4	1.4	1.2	1.3	1.1	1.8	0.5
Copepoda	9.7	16.5	27.6	45.4	74.8	43.6	141.1	299.3	61.6
Hyperiidea	1.5	1.4	4.4	2.7	3.7	2.6	3.7	3.4	1.6
Gammaridea	0.5	0.5	1.4	0.3	0.3	0.3	0.8	1.1	0.3
Other Taxa	1.5	0.5	4.1	3.4	4.5	3.2	2.5	2.8	1.1
All Zooplankton	35.1	13.0	100.0	104.2	68.7	100.0	229.2	327.2	100.0

Table 8. Mean biomass of zooplankton (mg/m^3 ± s.d.) in oblique tows taken through and below four surface water mass types. The percent of total zooplankton biomass represented by each taxon is also shown.

	Intense Plume			Diffuse Plume			Diffuse/Arctic			Arctic Water		
Taxon	Mean ± s.d.		%	Mean ± s.d.		%	Mean ± s.d.		%	Mean ± s.d.		%
Hydrozoa	4.9	0.0	4.6	18.0	12.3	12.6	13.4	7.7	6.1	12.2	6.3	3.7
Ctenophora	7.3	0.0	6.9	6.7	7.0	4.7	8.9	12.6	4.0	8.3	11.6	2.6
Pteropoda	1.1	0.0	1.0	1.9	2.7	1.3	2.2	2.2	1.0	2.0	1.2	0.6
Chaetognatha	10.6	0.0	10.0	4.6	4.2	3.2	23.0	28.4	10.4	5.0	2.5	1.5
Pisces	0.0	0.0	0.0	9.5	9.8	6.7	11.9	16.8	5.4	1.9	1.8	0.6
Mysidacea	54.2	0.0	51.1	5.3	8.9	3.7	7.9	13.0	3.6	1.8	3.6	0.6
Euphausiacea	0.6	0.0	0.5	2.4	3.5	1.7	13.2	34.9	6.0	8.0	17.5	2.4
Decapoda	0.0	0.0	0.0	0.8	1.0	0.6	0.5	0.6	0.2	0.3	0.6	0.1
Copepoda	14.6	0.0	13.8	88.1	87.9	61.5	132.4	94.4	60.0	281.1	258.7	86.3
Hyperiidea	0.0	0.0	0.0	2.2	3.0	1.5	2.7	2.2	1.2	2.5	1.9	0.8
Gammaridea	2.1	0.0	2.0	0.5	0.6	0.3	0.4	0.5	0.2	0.2	0.1	0.1
Other Taxa	10.7	0.0	10.1	3.0	3.4	2.1	4.1	2.7	1.8	2.5	2.9	0.8
All Zooplankton	106.1	0.0	100.0	143.2	95.3	100.0	220.6	126.7	100.0	325.8	278.6	100.0
Sample size	1			32			7			5		

However, a limited comparison of species composition in the various water masses is instructive. It shows that L. macrurus was very abundant in Arctic water and, to a lesser degree, in mixed diffuse plume/Arctic water; L. macrurus was scarce in diffuse plume water. These trends were evident both at the surface and at depth, although L. macrurus was more abundant at depth (Table 9). C. hyperboreus and C. glacialis were more narrowly distributed; substantial biomasses occurred only in Arctic water at depth. None of the species or taxa shown on Tables 6, 7 and 9 reached maximum abundance in diffuse plume water.

Zooplankton at a Front

Satellite images showed that turbid fronts were often found in Mackenzie Bay (Figs. 32-36). We were directed to one such front, visible to aerial surveyors on 7 September (six bowheads seen on seaward [clear] side of front; L. Harwood, pers. comm.), and sampled on both sides of the turbidity interface on 8 September (no whales were seen from the ship but high winds minimized viewing opportunities). In addition to the change in turbidity, this front was also marked by a rather large change in surface temperature (Fig. 38). Zooplankton biomass was twice as high on the clear, cold side of the front (Station 203 on Figs. 6, 38) as on the turbid, warm side of the front (Stations 201 and 202 on Fig. 6, Table 10). At these stations, mysids were dominant taxa, whereas copepods were the dominant taxa at other stations. Biomasses of mysids and copepods in horizontal tows taken at 9-10 m depth were about three times higher on the clear side of the front than on the turbid side. Calanus glacialis was the dominant copepod in samples taken on both sides. Biomass of Limnocalanus macrurus was <1 mg/m^3 in all samples. Again, biomass in water with Mackenzie River influences (water at depth on turbid side, and at surface on both sides) was lower than in water that showed some Arctic water influences. The higher biomass found on the clear side of the front was similar to the mean biomass taken in horizontal tows in Arctic water or diffuse/Arctic water (Table 7 vs. 10). Maximum biomass in any one horizontal tow was only 281 mg/m^3. Thus, we found no evidence of unusually high biomass near this front. It should be emphasised, however, that we did not conduct a thorough investigation of this front and that biomasses at other depths or locations near the front could have been quite different.

Table 9. Mean biomass of dominant zooplankton species taken in selected horizontal tows taken at the surface and at depth in different water masses. Also shown is the percent of mean total zooplankton biomass represented by each species. Most of these samples were taken near feeding whales; they are not representative of the study area as a whole.

	Diffuse Plume		Diffuse/Arctic		Arctic Water	
At Depth	mg/m^3	%	mg/m^3	%	mg/m^3	%
Total Biomass	25.0		182.0		376.2	
Copepoda	0.7	2.8	164.3	90.3	289.1	76.8
Limnocalanus macrurus	0.0	0.0	157.1	86.3	212.4	56.5
Calanus hyperboreus	0.4	1.6	1.1	0.6	29.7	7.9
Calanus glacialis	0.3	1.2	5.9	3.2	34.8	9.2
Aglantha digitale	3.9	15.7	1.0	0.6	15.6	4.1
Spiratella helicina	7.6	30.5	2.9	1.6	3.6	1.0
Gadidae YOY	4.5	18.1	1.0	0.5	7.9	2.1
Mysis litoralis	0.0	0.0	1.0	0.5	15.7	4.2
Thysanoessa raschii	0.0	0.0	1.3	0.7	6.2	1.7
Parathemisto libellula	0.0	0.0	0.3	0.2	1.9	0.5
Sample size	3		4		26	

	Diffuse Plume		Diffuse/Arctic		Arctic Water	
Surface Tows	mg/m^3	%	mg/m^3	%	mg/m^3	%
Total Biomass	4.0		46.8		90.7	
Copepoda	0.9	22.6	41.5	88.7	86.4	95.3
Limnocalanus macrurus	0.5	13.3	39.2	83.8	84.3	93.0
Calanus hyperboreus	0.2	5.7	0.0	0.0	0.4	0.4
Calanus glacialis	0.1	2.7	2.1	4.4	1.5	1.7
Halitholus cirratus	0.3	6.4	1.5	3.3	0.4	0.5
Aglantha digitale	0.3	8.3	0.8	1.7	1.3	1.4
Aeginopsis laurentii	0.0	0.4	0.0	0.0	0.1	0.2
Mertensia ovum	0.2	6.1	1.5	3.3	0.0	0.0
Spiratella helicina	0.1	2.9	0.2	0.4	1.3	1.5
Sagitta elegans	0.0	0.3	0.1	0.3	0.0	0.0
Gadidae YOY	0.0	0.0	0.0	0.0	0.0	0.0
Mysis litoralis	0.0	0.0	0.0	0.0	0.1	0.1
Sample size	5		1		4	

Table 10. Mean biomass (mg/m^3) in horizontal tows taken at depths of 9 to 10 m and at the surface on both sides of a visible front between Mackenzie River water and clear oceanic water in Mackenzie Bay. Also shown is the percent of mean total zooplankton biomass represented by each taxon.

	Turbid Side of Front			Clear Side of Front		
Taxon	Mean ± s.d.		%	Mean ± s.d.		%
Tows taken at 9-10 m						
Sample size		4			4	
Hydrozoa	34.4	20.6	38.6	21.6	15.3	12.8
Ctenophora	1.0	0.9	1.1	1.6	1.6	0.9
Pteropoda	0.0	0.0	0.0	0.1	0.1	0.1
Chaetognatha	0.3	0.4	0.4	1.3	0.9	0.8
Pisces	14.6	20.3	16.3	24.2	27.2	14.4
Mysidacea	23.7	26.0	26.5	76.8	64.2	45.5
Euphausiacea	1.2	1.8	1.4	1.7	1.8	1.0
Decapoda	0.3	0.6	0.4	0.8	0.5	0.5
Copepoda	9.7	9.1	10.8	32.9	9.7	19.5
Hyperiidea	3.0	3.6	3.3	3.8	4.3	2.3
Gammaridea	0.0	0.0	0.0	0.2	0.1	0.1
Other Taxa	1.0	0.7	1.1	3.7	3.2	2.2
All Zooplankton	89.3	67.0	100.0	168.6	94.4	100.0
Surface Tows						
Sample size		4			4	
Hydrozoa	0.3	0.2	26.7	0.8	0.5	17.0
Ctenophora	0.0	0.0	0.2	3.0	4.1	63.2
Pteropoda	0.0	0.0	0.2	0.0	0.0	0.5
Chaetognatha	0.0	0.0	2.9	0.0	0.0	0.4
Pisces	0.0	0.0	0.0	0.0	0.0	0.0
Mysidacea	0.0	0.0	0.0	0.0	0.1	0.6
Euphausiacea	0.0	0.1	2.3	0.0	0.0	0.0
Decapoda	0.0	0.0	0.6	0.0	0.0	0.0
Copepoda	0.7	0.3	57.4	0.8	0.5	16.4
Hyperiidea	0.0	0.0	1.5	0.0	0.0	0.0
Gammaridea	0.0	0.0	1.5	0.0	0.0	0.1
Other Taxa	0.1	0.1	6.9	0.1	0.1	1.9
All Zooplankton	1.2	0.7	100.0	4.7	4.7	100.0

Depth

Both total water depth and depth of a sample within the water column can affect zooplankton biomass. All of our samples were taken in the upper 50 m of the water column where biomass is generally higher than that found deeper in the water column (Buchanan and Sekerak 1982). Biomasses of fish larvae, euphausiids and mysids in oblique tows were higher in shallow water than in deep water (Table 4). Biomasses of all zooplankton and of copepods were also different over different depth ranges, but the direction of difference depended on area.

Mean biomass was an order of magnitude lower in surface horizontal tows than in samples taken below the surface (Table 11). Surface waters were generally influenced by Mackenzie River outflow and, as shown above, Mackenzie River water contained a lower biomass of zooplankton than did Arctic water. Below the surface, there was little difference in biomass between the three depth strata considered (Table 11).

Multiple Regression Analysis

Vertical profiles of several physical variables were recorded at each station. Biomass of zooplankton taken in horizontal tows was matched with physical data taken at the appropriate depth. In order to determine which physical variables were important predictors of the abundance of zooplankton biomass, multiple regression analysis was performed using physical and biomass data from 97 horizontal tows. Temperature, transmissivity (a measure of turbidity), and water density as well as the ranges in these parameters within a meter of the tow depth were used in the analysis (Table 12). Additional variables measuring the vertical change in density just above and below the tow depth were also considered in the analysis (Table 12).

As is to be expected, many of the physical variables used in the analysis were significantly correlated with one another (Table 13). Temperature was highly correlated with density, and temperature difference was highly correlated with density difference (Table 13). Generally, both warm temperatures and low salinity contributed to low density (Mackenzie River

Table 11. Mean biomass of major taxa in horizontal tows taken within four sampling depth ranges in the Southeastern Beaufort Sea in August and September 1986. The percent of mean total zooplankton biomass represented by each taxon is also shown.

	Sample Depth Range							
	Surface		2-10 m		11-20 m		>20 m	
Taxon	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%
Sample Size	52		57		39		8	
All Zooplankton	14.2	100.0	150.6	100.0	159.5	100.0	102.7	100.0
Hydrozoa	2.5	17.7	11.1	7.4	21.2	13.3	12.6	12.3
Ctenophora	2.2	15.2	4.0	2.6	5.6	3.5	8.7	8.4
Pteropoda	0.3	2.1	2.1	1.4	5.5	3.4	1.6	1.6
Chaetognatha	0.1	0.7	2.2	1.5	5.9	3.7	1.4	1.4
Pisces	0.3	2.3	5.7	3.8	9.5	5.9	5.4	5.3
Mysidacea	0.2	1.1	10.5	7.0	8.4	5.3	0.0	0.0
Euphausiacea	0.1	0.7	1.5	1.0	7.6	4.7	1.2	1.2
Decapoda	0.0	0.0	0.9	0.6	1.1	0.7	0.4	0.4
Copepoda	8.2	57.7	108.2	71.8	88.9	55.8	65.3	63.6
Hyperiidea	0.1	0.6	2.3	1.5	2.7	1.7	2.0	1.9
Gammaridea	0.1	0.4	0.4	0.2	0.7	0.5	0.4	0.4
Other Taxa	0.2	1.5	1.9	1.2	2.4	1.5	3.6	3.5

Table 12. Variables used in the multiple regression analysis of the relationship between total zooplankton biomass in horizontal tows and physical variables.

Variable	Definition and Units	Range of Values
Station Depth	Water depth at station (m)	10 to 167
Tow Depth	Depth of plankton tow (m)	2 to 40
Temperature	Mean temp. within 1 m of tow depth (°C)	-1.5 to 6.4
Temp. Difference	Max.- min. temp. within 1 m of tow depth (C°)	0 to 4.3
Transmissivity	Percent of light transmitted through a 25 cm light path. Attenuance = -0.04 ln (transmissivity)	1 to 92
Trans. Difference	Max. - min. transmissivity within 1 m of tow depth	0 to 78
Density	Mean water density within 1 m of tow depth (σ_t)	13.2 to 26.2
Density Difference	Max. - min. density within 1 m of tow depth	0 to 8.4
Density Diff. + 2 m	Max. - min. density in the 2 m above tow depth	0.3 to 18.3
Density Diff. - 2 m	Max. - min. density in the 2 m below tow depth	4.8 to 23.6
Total Biomass	Log transformed total biomass of zooplankton in horizontal tows (log mg/m^3)	0.4 to 3.2

Table 13. Pearson product-moment correlation matrix of measurements of physical variables recorded with each horizontal plankton tow. Significance levels are shown by asterisks (* P<0.05; ** P<0.01; *** P<0.001). Analysis was based on 97 samples; physical variables are described in Table 12.

	Station Depth	Tow Depth	Temperature	Temp. Diff.	Transmissivity	Trans. Diff.	Density	Density Diff.	Density Diff. + 2 m
Tow Depth	0.09								
Temperature	-0.21 *	-0.77 ***							
Temp. Difference	0.11	-0.16	0.02						
Transmissivity	0.50 ***	0.35 ***	-0.28 **	-0.07					
Trans. Difference	-0.37 ***	-0.21 *	0.15	0.28 **	-0.50 ***				
Density	0.04	0.72 ***	-0.90 ***	-0.04	0.13	0.01			
Density Difference	0.03	-0.32 ***	0.25 *	0.82 ***	-0.13	0.44 ***	-0.25 *		
Density Diff. + 2 m	0.10	-0.27 **	0.24 *	0.35 ***	-0.15	0.52 ***	-0.21 *	0.55 ***	
Density Diff. - 2 m	0.13	-0.12	0.08	0.16	0.13	-0.19	-0.10	0.24	0.06

influence) and both low temperature and high salinity contributed to high density (Fig. 13). Temperature was negatively correlated with tow depth because warm water was generally found near the surface and cold water at deeper depths. When predictor variables are strongly inter-correlated, as was the case here, it is usually not possible to determine which of those variables is (or are) of direct importance to the animals.

A multiple regression equation containing the only two significant predictor variables, transmissivity and density, accounted for 42% of the variance in total zooplankton biomass (log transformed) in the 97 horizontal tows (Table 14). Biomass was highest in water of high density (low temperature and high salinity) and low transmissivity (high turbidity). Because high turbidity was usually associated with warm freshened (low density) water of the Mackenzie plume and not high density Arctic water, these results imply that high biomass was associated with high turbidity of local origin rather than Mackenzie River origin. For example, the two stations with the highest biomass in horizontal tows (Stn 2 and 3) were located close to the Yukon coast. High turbidity in this region was due to local resuspension of bottom sediments (see Subsurface Distributions).

Tow depth and temperature were also correlated with biomass (Table 14). Biomass was highest in deeper colder water. Because these two variables were correlated with density, they were not of significant additional utility as predictive of zooplankton biomass after inclusion of the density term. The low correlations between biomass and vertical differences in temperature and density imply that aggregations of zooplankton did not occur at density interfaces.

Summary

The results of the multiple regression analysis (Table 14), along with data on biomass vs. water mass type (Tables 6, 7 and 8), show that zooplankton biomass was higher in Arctic water than in water influenced by Mackenzie River water. Biomass in oblique tows through and below surface water with Arctic water characteristics was higher than that in oblique tows taken through surface water influenced by the Mackenzie River plume (Table 8). All of these

Table 14. Results of correlation and stepwise multiple regression analyses[a] of the total biomass of zooplankton in horizontal bongo tows in relation to physical variables. Nominal significance levels are shown by asterisks (* $P<0.05$; ** $P<0.01$; *** $P<0.001$); significance levels for individual variables considered in a stepwise multiple regression analysis are approximate. Variables denoted by '-' were not of significant value as predictors of biomass after other variables were considered (nominal $P>0.05$) and were excluded from the equation. Physical variables are described in Table 12.

	Simple Correlation Coefficients	Coefficients for Multiple Regression Eq'n
Constant (Y-intercept)		0.395
Station Depth	-0.17	-
Tow Depth	0.25 **	-
Temperature	-0.39 ***	-
Temp. Difference	0.11	-
Transmissivity	-0.36 ***	-0.012 ***
Trans. Difference	0.13	-
Density	0.50 ***	0.101 ***
Density Difference	-0.07	-
Density Diff. + 2 m	-0.16	-
Density Diff. - 2 m	-0.19	-
Multiple _R_		0.66 ***
% of variance explained		42%
SE of estimate		0.44
Sample Size		97

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[a] The regression coefficient of each variable that entered the equation is shown along with the constant (Y-intercept) and statistics describing the fit of the equation. Biomass transformed to log(mg/m^3) prior to analysis.

results show that biomass in 1986 was highest in water that was unaffected by Mackenzie River water and lowest where Mackenzie River influences were greatest.

Distribution of Zooplankton and Whales

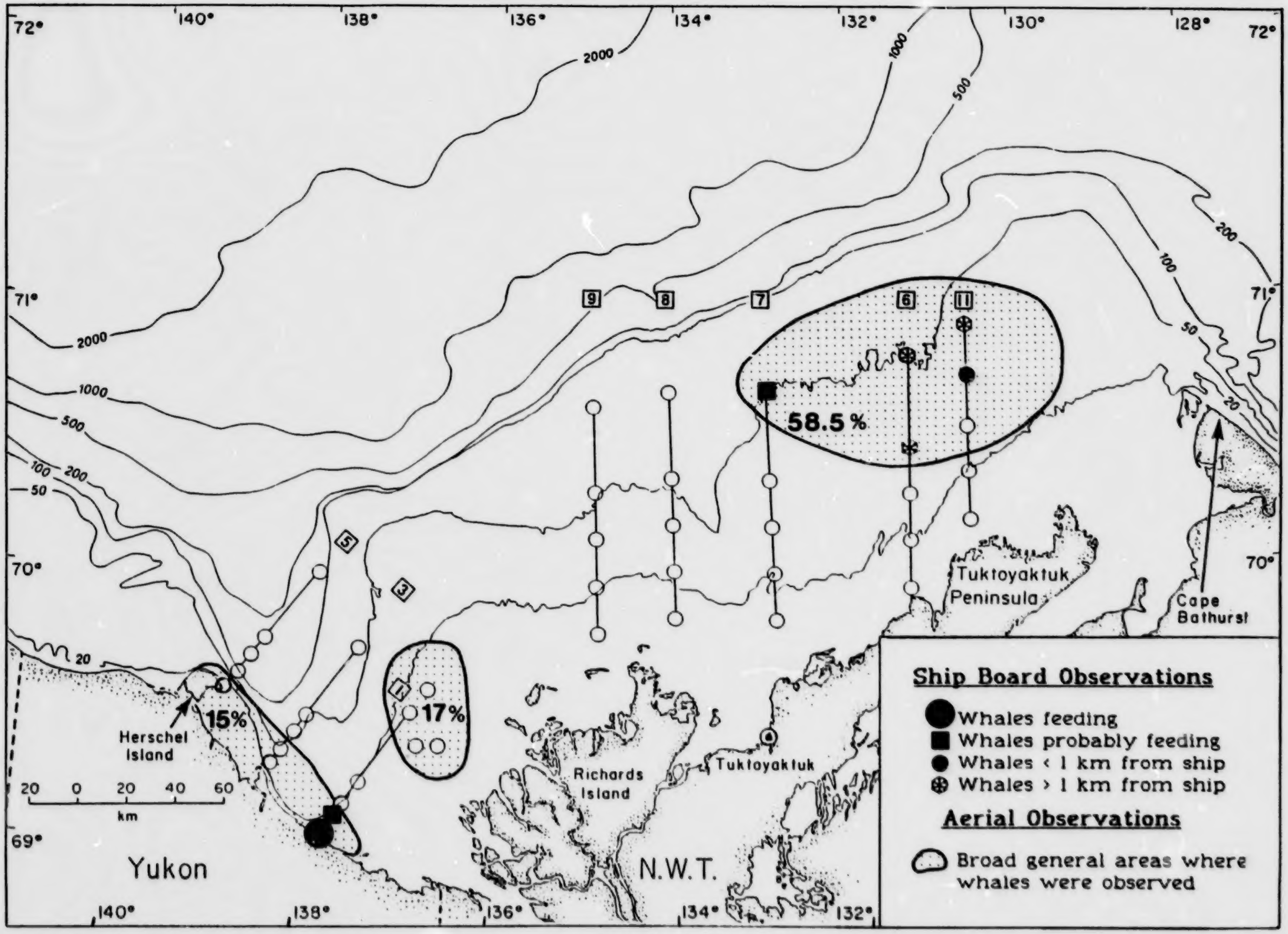
Bowheads were observed from the ship (this study) and during aerial surveys conducted concurrently with our field sampling (Harwood and Norton 1986; Ford et al. in prep.). In the following section we have categorized zooplankton sampling stations on the basis of the presence or apparent absence of whales. We compare zooplankton biomass in areas where whales were and were not observed. A later section gives details about zooplankton and the physical regime at specific whale feeding locations.

Zooplankton vs. Proximity of Whale

Harwood and Norton (1986) and Ford et al. (in prep.) conducted aerial surveys for bowhead whales from 25 August-1 September and from 7-14 September 1986. Zooplankton sampling stations were categorized as being within or outside areas where whales were observed during these surveys (Fig. 39). Fifteen stations were categorized as being within areas where whales were observed. These 15 stations included seven stations where whales were observed from the ship (Fig. 39).

Mean biomasses of zooplankton in horizontal, oblique and surface tows at the 15 stations within areas where whales were observed were substantially higher than those in areas where no whales were observed (Table 15). Biomass in horizontal tows at depth was three times higher and biomass in surface tows was five times higher at stations within areas where whales were observed from the air than elsewhere. Average biomass in the water column as measured with oblique tows was twice as high within areas where whales were observed from the air as elsewhere.

In each type of tow, the mean biomass of copepods was much higher in the areas where whales were observed. In horizontal tows, biomasses of mysids and euphausiids were also much higher in the areas where whales were observed. In


72°
140°
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71°
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2000
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9
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11
5
3
1
58.5 %
17%
15%
Herschel Island
20 0 20 40 60
km
Yukon
N.W.T.
Richards Island
Tuktoyaktuk
Tuktoyaktuk Peninsula
Cape Bathurst
Ship Board Observations
Whales feeding
Whales probably feeding
Whales < 1 km from ship
Whales > 1 km from ship
Aerial Observations
Broad general areas where whales were observed

Figure 39. Stations where bowhead whales were observed from the ship, and general areas where bowheads were observed during aerial surveys conducted by Ford et al (in prep) and Harwood and Norton (1986). Percentages indicate % of all on-transect bowheads seen in areas indicated (both surveys combined). 8.5% of bowhead sightings were outside these three areas.

Table 15. Mean biomasses (mg/m^3) of the major groups of zooplankton in tows within areas where whales were observed during aerial surveys conducted by Harwood and Norton (1986, in prep.). Also shown is the percent of mean total zooplankton biomass represented by each taxon that is listed.

	Areas Where Whales were Observed			Areas Where no Whales were Observed		
Taxon	Mean ± s.d.		%	Mean ± s.d.		%
Horizontal Tows at Depth[a]						
Sample size	20			28		
Hydrozoa	26.1	24.2	8.4	16.7	21.4	16.6
Ctenophora	4.5	7.6	1.4	7.7	10.5	7.6
Mysidacea	26.2	39.7	8.4	7.6	23.0	7.5
Euphausiacea	14.3	23.2	4.6	1.9	4.2	1.9
Copepoda	207.4	373.1	66.6	42.1	76.4	41.9
All Zooplankton	311.6	392.4		100.5	112.4	
Oblique Tows						
Sample size	11			35		
Hydrozoa	13.1	8.8	4.3	17.5	11.7	13.5
Ctenophora	10.4	11.6	3.4	6.2	6.8	4.8
Mysidacea	5.1	9.0	1.7	6.6	12.3	5.1
Euphausiacea	12.6	28.9	4.1	2.1	3.4	1.6
Copepoda	238.9	195.4	78.2	72.6	62.6	55.9
All Zooplankton	305.6	210.6		129.9	70.3	
Surface Tows						
Sample size	19			33		
Hydrozoa	4.3	14.4	15.1	1.5	2.3	24.7
Ctenophora	1.1	2.1	3.7	2.8	7.2	46.1
Mysidacea	0.0	0.1	0.1	0.2	0.9	3.9
Euphausiacea	0.0	0.1	0.2	0.1	0.7	2.0
Copepoda	21.2	77.5	74.4	0.8	1.3	12.5
All Zooplankton	28.5	80.2		6.1	7.4	

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[a] Within layers of zooplankton that were evident on the echosounder.

contrast, biomasses of ctenophores and hydrozoans were similar in the two categories of stations.

Whales were determined to be actively feeding at one of the shipboard sampling stations, probably feeding at two other stations, and present within 1 km of the ship at one other station. Whales were observed at distances of more than 1 km from the ship at three additional stations (Fig. 39). The apparent absence of whales near the ship at some stations within the general area where whales were observed from the air is not surprising, since most bowheads move away when ships approach within 1-4 km (Richardson et al. 1985b). Even so, mean biomasses in oblique tows at depth and surface tows were all highest at stations where whales were observed within 1 km of the ship (Table 16). Mean biomasses in horizontal and surface tows were six times higher at stations where whales were observed within 1 km than at stations where no whales were observed. Mean biomass in oblique tows within 1 km of whales was more than twice as high as that where whales were observed >1 km away, and four times higher than at stations where no whales were seen.

The mean biomasses of copepods were much higher in all types of tows within 1 km of whales than at other stations. These differences in copepod biomass accounted for most of the differences in total biomass among the three groups of stations (Table 16). The mean biomasses of euphausiids in oblique and horizontal tows were also much higher within 1 km of whales than elsewhere, although even near whales euphausiids accounted for only a low proportion of total biomass (Table 16). Biomasses of hydrozoans, ctenophores and mysids were all generally low, and not appreciably higher near whales than elsewhere.

The physical oceanographic regime and species composition of the zooplankton at each of the stations where whales were observed <1 km from the ship are described in the following section.

Zooplankton in Specific Whale Feeding Areas

Whales were observed to be feeding at one sampling station and were probably feeding at two other stations sampled from the ship. Whales were

Table 16. Mean biomass (mg/m^3) of the major groups of zooplankton in tows taken at stations where whales were observed at a distance of less than 1 km from the ship, more than 1 km from the ship, and at stations where no whales were observed. Where no whales were observed from the ship samples are categorized as being within or outside of areas where whales were observed from the air. Also shown is the percent of mean total zooplankton biomass represented by each taxon that is listed.

							No Whales Observed From Ship					
	Whales <1 km			Whales >1 km			Whales Seen from Air			No Whales from Air		
Taxon	Mean ± s.d.		%	Mean ± s.d.		%	Mean ± s.d.		%	Mean ± s.d.		%
Horizontal Tows at Depth[a]												
Sample size	7			1			12			28		
Hydrozoa	31.3	33.7	4.7	6.0	0.0	11.3	24.8	18.3	20.1	16.7	21.4	16.6
Ctenophora	4.2	4.5	0.6	31.1	0.0	59.0	2.4	4.4	2.0	7.7	10.5	7.6
Mysidacea	16.8	15.6	2.5	0.0	0.0	0.0	33.8	49.1	27.5	7.6	23.0	7.5
Euphausiacea	39.0	24.7	5.8	0.0	0.0	0.0	1.1	1.4	0.9	1.9	4.2	1.9
Copepoda	534.9	493.2	79.6	0.3	0.0	0.5	33.5	52.0	27.3	42.1	76.4	41.9
All Zooplankton	671.9	489.0		52.7	0.0		122.9	89.2		100.5	112.4	
Oblique Tows												
Sample size	4			3			4			35		
Hydrozoa	11.8	5.8	2.2	18.3	13.9	8.3	10.7	7.7	7.4	17.5	11.7	13.5
Ctenophora	5.8	4.4	1.1	18.1	15.0	8.2	9.2	13.9	6.4	6.2	6.8	4.8
Mysidacea	9.7	13.4	1.8	0.3	0.5	0.1	4.0	6.2	2.8	6.6	12.3	5.1
Euphausiacea	32.9	43.8	6.2	0.0	0.0	0.0	1.8	2.1	1.3	2.1	3.4	1.6
Copepoda	438.8	195.1	82.5	161.2	64.6	73.6	97.3	19.3	67.4	72.6	62.6	55.9
All Zooplankton	531.7	175.4		219.1	90.3		144.4	36.6		129.9	70.3	
Surface Tows												
Sample size	4			3			12			33		
Hydrozoa	1.5	1.3	1.5	2.2	2.0	39.9	5.8	18.2	54.8	1.5	2.3	24.7
Ctenophora	0.7	0.7	0.7	0.9	1.1	16.9	1.2	2.6	11.6	2.8	7.2	46.1
Mysidacea	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.3	0.2	0.9	3.9
Euphausiacea	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.2	0.5	0.1	0.7	2.0
Copepoda	95.7	163.2	96.1	1.6	1.9	27.8	1.2	1.5	11.9	0.8	1.3	12.5
All Zooplankton	99.5	166.6		5.6	5.7		10.5	24.8		6.1	7.4	

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[a] Within layers of zooplankton that were evident on the echosounder.

seen within 1 km of the ship at one additional station (Fig. 39). The biomass and species composition of the zooplankton at each of these four stations is described below.

Station 2.--This station was located in 14 m of water just off the Yukon coast and was sampled on 5 September 1986. About 12 whales were observed all around the ship. They were diving repeatedly with 'fluke out' dives. These observations suggested that the whales were feeding below the surface (_cf._ Würsig et al. 1985).

Diffuse plume water was found at the surface over much of the region off the Yukon coast. Before the sampling time, offshore winds had pushed diffuse plume water offshore. This water was replaced with cold saline water from about 10 to 15 m depth. This was one of the few stations at which Arctic water was found at the surface. Arctic water was found below the surface at all stations. On this transect, Mackenzie River influences at the surface increased with increasing distance from shore, and as a result, the pycnocline became more intense with increasing distance from shore. The pycnocline at station 2 was less well developed than at any other stations on Transect 1 (Fig. 17).

The biomasses of zooplankton in the surface tow, oblique tow and 4 of 5 horizontal tows were higher than any others taken within their respective categories during this study. The horizontal and oblique tow data show that a high biomass was found throughout the water column (Table 17A). Maximum biomass found at this station was 1543 mg/m^3 at a depth of 3 m. _Limnocalanus macrurus_ was the dominant zooplankter in all tows. Biomass and species composition of the zooplankton at this station were similar to those of zooplankton near feeding whales off the same part of the Yukon coast in late August 1985, and farther west off Komakuk (Yukon) and the Kongakut Delta (Alaska) in early September 1986 (Bradstreet and Fissel 1986; Griffiths et al. 1987). Conditions at this station could be considered as typical of a nearshore bowhead feeding ground on the Yukon coast.

Table 17. Composition of zooplankton in horizontal and oblique tows collected near bowhead whales at 4 locations in the Southeastern Beaufort Sea in August and September 1986.

A. Station 2, 14 m water depth off the Yukon Coast, 5 Sept 86.
About 12 whales all around ship, diving and fluking out

	Horizontal Tows												Oblique Tow	
Sample Depth (m) ->	1		3		5.2		8.5		11		12.5		10	
	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%
All Zooplankton	347.5		1542.9		1469.1		1438.1		718.4		1114.4		776.4	
Hydrozoa	2.7	0.8	4.1	0.3	8.4	0.6	23.3	1.6	21.1	2.9	20.8	1.9	7.5	1.0
Chaetognatha	0.4	0.1	3.5	0.2	3.7	0.3	10.9	0.8	20.5	2.9	9.6	0.9	5.6	0.7
Mysidacea	0.2	0.1	4.5	0.3	6.9	0.5	10.4	0.7	19.5	2.7	26.4	2.4	8.2	1.1
Euphausiacea	0.2	0.1	2.5	0.2	3.6	0.2	31.1	2.2	45.0	6.3	38.4	3.4	39.2	5.1
Copepoda	338.8	97.5	1523.3	98.7	1437.7	97.9	1350.4	93.9	590.7	82.2	999.5	89.7	706.2	91.0
Limnocalanus macrurus	337.4	97.1	1461.7	94.7	1396.7	95.1	1138.9	79.2	398.6	55.5	884.9	79.4	667.0	85.9
Calanus hyperboreus	0.2	0.1	3.5	0.2	8.4	0.6	100.2	7.0	136.4	19.0	44.3	4.0	17.7	2.3
Calanus glacialis	0.8	0.2	58.2	3.8	32.5	2.2	102.3	7.1	45.1	6.3	69.8	6.3	18.8	2.4
Aglantha digitale	2.5	0.7	2.5	0.2	6.2	0.4	16.0	1.1	19.6	2.7	13.6	1.2	6.0	0.8
Sagitta elegans	0.0	0.0	1.9	0.1	2.9	0.2	9.9	0.7	19.2	2.7	9.1	0.8	3.9	0.5
Mysis litoralis	0.2	0.1	4.4	0.3	6.9	0.5	10.4	0.7	19.5	2.7	26.3	2.4	8.2	1.1
Thysanoessa raschii	0.2	0.1	2.5	0.2	3.6	0.2	24.2	1.7	40.6	5.7	30.9	2.8	37.3	4.8
Total of common species		98.3		99.5		99.2		97.5		94.6		96.9		97.8

B. Station 3, 21 m water depth off the Yukon Coast, 5 Sept 86.
3 whales seen near ship possibly feeding

	Horizontal Tows										Oblique Tow	
Sample Depth (m) ->	1.0		2.1		8.5		11.0		14.0		18	
	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%	mg/m^3	%
All Zooplankton	45.7		640.0		293.6		286.5		770.5		454.8	
Hydrozoa	2.3	5.1	4.8	0.7	46.9	16.0	3.3	1.2	100.2	13.0	10.0	2.2
Ctenophora	1.5	3.3	1.7	0.3	12.0	4.1	0.3	0.1	8.4	1.1	2.9	0.6
Chaetognatha	0.1	0.3	0.0	0.0	22.7	7.7	30.6	10.7	63.1	8.2	27.6	6.1
Mysidacea	0.0	0.0	0.1	0.0	7.5	2.6	7.8	2.7	46.2	6.0	29.1	6.4
Euphausiacea	0.0	0.0	0.0	0.0	29.9	10.2	82.8	28.9	46.1	6.0	92.4	20.3
Copepoda	41.5	90.7	628.6	98.2	158.8	54.1	151.8	53.0	492.4	63.9	275.3	60.5
Limnocalanus macrurus	39.2	83.8	628.3	98.2	34.5	11.7	20.1	7.0	84.5	11.0	116.8	25.7
Calanus hyperboreus	0.0	0.0	0.0	0.0	47.9	16.3	33.5	11.7	68.5	8.9	81.9	18.0
Calanus glacialis	2.1	4.4	0.0	0.0	71.1	24.2	92.4	32.3	78.1	10.1	62.6	13.8
Aglantha digitale	0.8	1.7	1.4	0.2	41.2	14.0	0.2	0.1	95.1	12.3	8.9	2.0
Sagitta elegans	0.1	0.3	0.0	0.0	22.6	7.7	30.1	10.5	46.9	6.1	26.6	5.8
Mysis litoralis	0.0	0.0	0.0	0.0	7.5	2.6	7.8	2.7	46.2	6.0	29.1	6.4
Thysanoessa inermis	0.0	0.0	0.0	0.0	5.8	2.0	17.1	6.0	11.3	1.5	15.9	3.5
Thysanoessa inermis A	0.0	0.0	0.0	0.0	7.7	2.6	55.8	19.5	14.7	1.9	21.9	4.8
Thysanoessa raschii	0.0	0.0	0.0	0.0	16.4	5.6	9.9	3.4	19.8	2.6	54.6	12.0
unidentified copepoda	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2	242.9	31.5	0.0	0.0
Total of Common species		90.2		98.4		86.7		93.4		91.9		92.0

Table 17. Continued.

C. Station 60, 49 m water depth north of Tuktoyaktuk, 30 Aug 86.
Whales within 50 m of ship, possibly feeding.

	Horizontal Tows				Oblique Tow	
Sample Depth (m) ->	1.0		17.0		47	
	mg/m³	%	mg/m³	%	mg/m³	%
All Zooplankton	2.7		60.3		368.9	
Hydrozoa	0.6	21.9	2.8	4.7	20.3	5.5
Ctenophora	0.2	5.6	1.1	1.8	9.4	2.5
Pteropoda	0.0	0.4	7.3	12.1	2.9	0.8
Chaetognatha	0.0	0.7	0.2	0.3	8.2	2.2
Pisces	0.0	0.0	2.9	4.9	4.2	1.1
Copepoda	1.6	59.9	40.1	66.5	314.4	85.2
Hyperiidea	0.0	0.0	4.3	7.1	3.0	0.8
Other Taxa	0.3	11.2	1.6	2.7	6.3	1.7
Calanus hyperboreus	0.1	4.5	39.0	64.7	279.0	75.6
Calanus glacialis	1.3	47.2	0.7	1.2	32.4	8.8
Halitholus cirratus	0.5	20.1	0.0	0.0	2.8	0.8
Spiratella helicina	0.0	0.4	7.3	12.1	2.6	0.7
Gadidae YOY	0.0	0.0	2.9	4.9	2.1	0.6
unidentified copepoda	0.2	5.9	0.0	0.0	0.0	0.0
Parathemisto libellula	0.0	0.0	4.2	7.0	2.0	0.5
Total of common species		78.1		89.9		87.0

D. Station 79, 36 m water depth off the eastern Tuktoyaktuk Peninsula, 3 Sept 86.
3 whales seen 500 m from boat

	Horizontal Tows								Oblique Tow	
Sample Depth (m) ->	1		4		13		21		34	
	mg/m³	%	mg/m³	%	mg/m³	%	mg/m³	%	mg/m³	%
All Zooplankton	2.1		13.1		81.9		273.4		526.6	
Hydrozoa	0.2	8.9	1.1	8.5	3.9	4.8	17.7	6.5	9.3	1.8
Ctenophora	1.1	50.2	0.0	0.3	5.2	6.3	40.7	14.9	9.8	1.9
Pteropoda	0.0	0.0	2.7	20.6	53.4	65.2	7.9	2.9	13.2	2.5
Pisces	0.0	0.0	5.7	43.3	16.4	20.1	10.2	3.7	9.1	1.7
Copepoda	0.9	40.8	0.7	5.4	0.9	1.0	177.5	64.9	459.3	87.2
Hyperiidea	0.0	0.0	0.0	0.1	0.1	0.1	6.9	2.5	3.7	0.7
Other Taxa	0.0	0.5	2.8	21.8	1.7	2.1	9.2	3.4	7.9	1.5
Calanus hyperboreus	0.7	32.4	0.6	5.0	0.4	0.5	151.8	55.5	362.0	68.7
Calanus glacialis	0.1	3.8	0.0	0.3	0.2	0.2	20.4	7.5	85.7	16.3
Aglantha digitale	0.1	5.2	0.0	0.0	0.4	0.5	10.3	3.8	5.0	0.9
Mertensia ovum	0.0	0.0	0.0	0.2	4.8	5.8	40.0	14.6	9.8	1.9
Spiratella helicina	0.0	0.0	2.7	20.6	53.4	65.2	7.8	2.8	13.2	2.5
Sagitta elegans	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.3	10.7	2.0
Gadidae YOY	0.0	0.0	4.8	36.5	16.4	20.1	9.3	3.4	6.9	1.3
Stichaeidae YOY	0.0	0.0	0.9	6.7	0.0	0.0	0.0	0.0	0.7	0.1
Total of common species		41.7		69.3		93.3		87.9		93.7

Station 3.--Station 3 was located just offshore of station 2 on Transect 1 and was also sampled on 5 September (Fig. 39). About three whales were observed near the ship. Their behaviour indicated that they were probably feeding.

The influence of the nearshore upwelling that was noted at station 2 was less evident at station 3. The surface water was a mixture of diffuse plume and Arctic water (Fig. 22). The vertical distribution of temperature and salinity show that stratification of the water column at this station was stronger than at station 2 but not as strong as that farther offshore on Transect 1 (Fig. 17).

Zooplankton biomass at the surface was much lower than at station 2 (Table 17B). Biomasses in the two horizontal tows with the highest biomasses were about half the values at station 2 (Table 17B vs. A). Biomass was lowest in tows taken near the thermocline (8.5 and 11 m, Table 17B. Appendix A). Biomass was higher above the pycnocline (but not at the surface) and below the pycnocline. Limnocalanus macrurus was the dominant zooplankter above the pycnocline. Calanus hyperboreus and C. glacialis dominated within and below the pycnocline (Table 17B).

Station 60.--This station was located in 49 m of water north of Tuktoyaktuk at the north end of Transect 7; it was sampled on 30 August. At least two whales were seen at this station. They came within 50 m of the ship and at least one was observed doing 'fluke out' dives. This was one of the stations where mixed Arctic water/diffuse plume water was present at the surface (Fig. 22). In this case, the presence of Arctic water/diffuse plume water at the surface was due to diminishing influence of the Mackenzie River Plume with increasing distance from shore (Figs. 22, 24, 30).

The echosounder was not functioning at this station, so we were unable to guide the net to layers of zooplankton with the echosounder. Biomass in an oblique tow taken at this station was comparable to that in oblique tows taken at the other three stations where whales were observed close to the ship, and much higher than the average biomass in the 39 oblique tows taken where no whales were observed:

	Whales Present				
	Stn 2	Stn 3	Stn 60	Stn 79	No Whales (n = 39)
All Zooplankton (mg/m^3)	776	455	369	527	131 ± s.d. 68

In the oblique tow taken at this station, Calanus hyperboreus accounted for 76% of total zooplankton biomass (Table 17C). Calanus glacialis was the other important contributor to total zooplankton biomass (9%).

Station 79.--This station was located in 36 m water depth off the Tuktoyaktuk Peninsula along our easternmost transect, and was sampled on 3 September (Fig. 39). Three bowheads were observed 500 m from the ship. Their behaviour at this time is unknown. The diffuse plume per se was not evident at this eastern station, although the surface water had been influenced by the diffuse plume (Figs. 22, 28).

Biomass in the oblique tow at this station was very high and comparable to that at other stations where whales were observed near the ship (Table 17). Total zooplankton biomass in the oblique tow (527 mg/m^3) was higher than in the horizontal tow with the highest biomass (273 mg/m^3, Table 17D). This indicates that we did not sample within the layer of highest biomass at this station. Biomass at the surface was negligible. Calanus hyperboreus was the dominant zooplankter in the horizontal tow with the highest biomass and in the oblique tow (69% of biomass). Calanus glacialis was the other dominant species in the oblique tow (16% of biomass).

Summary

Total zooplankton biomass was much higher in areas where whales were observed from the ship or from aircraft than in areas where whales were not observed. At two adjacent nearshore stations off the Yukon coast where we sampled near whales, *Limnocalanus macrurus* and *Calanus* spp. were the dominant zooplankton taxa. At two stations off the Tuktoyaktuk Peninsula where we sampled near whales, *Calanus hyperboreus* and *Calanus glacialis* were the dominant zooplankters. Diffuse plume water was found at the surface over most of the study area; however, Arctic water was present at the surface at two of the four stations where we sampled close to whales, and mixed Arctic/diffuse plume water was present at the other two.

CALORIC AND LIPID CONTENT OF ZOOPLANKTON

In summer, Arctic zooplankters have only a short period of time in which to store energy for the long winter when food is scarce. They store this energy in the form of lipids (Raymont 1983). In spring, lipid content of Arctic copepods is low, amounting to 29% of dry weight (Lee 1974). Caloric content increases between spring and fall (Percy and Fife 1980; Harris 1985). Lipid content is highest in August when it can amount to 74% of dry weight. Bowheads feed in the Canadian Beaufort Sea in late summer and early fall when caloric and lipid content of the zooplankton is at its highest. In the following section we discuss the energetic and lipid content of zooplankton that is available to feeding bowheads in the Southeastern Beaufort Sea.

Caloric Content

The caloric content of major species of zooplankton collected in August and September 1986 is shown in Table 18. 'Calories per gram dry weight' values determined in the laboratory were converted to cal/g wet weight using the dry:wet weight ratios shown in Table 19. The copepod *Calanus hyperboreus* and the euphausiid *Thysanoessa raschii* had the highest caloric content of any of the taxa that were analyzed; hydrozoans and ctenophores had the lowest (Table 18). All copepods had high caloric content, large copepods had slightly higher caloric content than medium-sized copepods, and small copepods had slightly less. However, these differences were not statistically significant (ANOVA $F = 1.3$, $df = 2,61$, $p = 0.29$).

Table 18. Ash and caloric content of various species and life stages collected in the Southeastern Beaufort Sea in late August and early September 1986. Data from each group and species were obtained by pooling data for species and/or life stages in that group.

	% Ash			Cal/g wet weight		Cal/g dry weight		
	Mean ± sd		n	Mean ± sd		Mean ± sd		n
Onisimus spp.	0.19	0.02	3	812	55	4892	329	3
Parathemisto libellula	0.13	0.04	7	821	64	4944	384	7
Calanus glacialis IV	0.16	0.06	8	799	127	4364	696	8
Calanus glacialis V	0.10	0.05	8	970	66	5299	361	8
Calanus glacialis F	0.07	0.02	7	949	95	5188	520	7
Calanus hyperboreus IV	0.10	0.03	8	976	47	5335	256	8
Calanus hyperboreus V	0.07	0.02	8	999	59	5459	321	8
Calanus hyperboreus F	0.07	0.01	8	960	82	5246	448	8
Derjuginia tolli V	0.09	0.03	2	803	114	4387	622	2
Euchaeta glacialis V	0.15	0.09	5	900	62	4917	341	5
Euchaeta glacialis F	0.14	0.05	2	714	379	3904	2071	2
Limnocalanus macrurus F	0.14	0.06	4	872	174	4763	951	4
Limnocalanus macrurus M	0.13	0.06	4	883	213	4824	1166	4
Decapod juveniles 12 mm	0.09	0.04	2	570	28	4253	209	2
Decapod juveniles 15 mm	0.10	0.06	7	546	59	4077	446	7
Thysanoessa raschii	0.07	0.03	8	1033	179	5218	904	8
Boreogadus saida	0.12	0.05	8	765	101	4550	600	8
Liparis spp.	0.10	0.05	4	777	39	4628	232	4
Stichaeidae YOY	0.13	0.03	8	788	39	4691	234	8
Aeginopsis laurenti	0.42	0.06	5	224	55	1965	484	5
Aglantha digitale	0.35	0.17	8	228	25	2004	218	8
Halitholus cirratus	0.54	0	1	138	0	1213	0	1
Mysis litoralis 12 mm	0.11	0.07	8	807	85	4017	424	8
Mysis litoralis 25 mm	0.10	0.07	8	1010	118	5024	587	8
Spiratella helicina	0.17	0.02	9	627	222	4480	1587	9
Sagitta elegans	0.17	0.06	8	291	49	4407	738	8
Beroe cucumis	0.62	0.05	3	141	34	1435	352	3
Mertensia ovum	0.39	0.04	5	236	46	2406	468	5
Life Stages Pooled								
Calanus glacialis	0.11	0.06	23	904	124	4940	675	23
Calanus hyperboreus	0.08	0.03	24	978	63	5347	347	24
Derjuginia tolli	0.09	0.03	2	803	114	4387	622	2
Euchaeta glacialis	0.14	0.08	7	847	186	4627	1018	7
Limnocalanus macrurus	0.13	0.06	8	877	180	4793	985	8
Decapod juveniles	0.10	0.06	9	552	54	4116	401	9
Mysis litoralis	0.11	0.07	16	909	144	4520	718	16
Copepods (all)	0.10	0.05	64	919	129	5023	704	64
< 1.8 mm	0.12	0.05	10	862	166	4712	910	10
1.8 - 4 mm	0.11	0.05	31	923	113	5042	617	31
> 4 mm	0.09	0.05	23	939	130	5132	710	23
Euphausiids	0.07	0.03	8	1033	179	5218	904	8
Mysids	0.11	0.07	16	909	144	4520	718	16
Amphipods	0.15	0.05	10	818	58	4928	350	10
Decapods	0.10	0.06	9	552	54	4116	401	9
Fish larvae	0.12	0.04	20	776	68	4622	407	20
Pteropods	0.17	0.02	9	627	222	4480	1587	9
Chaetognaths	0.17	0.06	8	291	49	4407	738	8
Hydrozoans	0.39	0.14	14	220	43	1934	376	14
Ctenophores	0.48	0.12	8	200	63	2042	643	8

Table 19. Mean dry weight expressed as a percentage of wet weight (± s.d.) for various zooplankton taxa taken in plankton tows in the eastern Alaskan Beaufort Sea in September 1986 (from Griffiths et al. 1987).

	Mean	s.d.	n
Copepods	18.3	1.1	5
Euphausiids	19.8	1.6	5
Mysids	20.1	1.2	5
Hyperiids	16.6	2.5	5
Chaetognaths	6.6	0.6	5
Hydrozoans	11.4	2.2	5
Ctenophores	9.8	1.8	5
Decapod larvae	13.4	1.3	5
Fish larvae	16.8	1.4	5

had slightly higher caloric content than medium-sized copepods, and small copepods had slightly less.

To assess the relative caloric content of zooplankton in various parts of the study area, the data in Table 18 were used to convert wet weight biomass to caloric content per cubic meter for each zooplankton sample. Considering all horizontal and oblique tows, caloric content per cubic meter was highest near bowhead whales (Table 20). Calories per gram wet weight was also highest in these areas. Mean calories per gram wet weight in horizontal tows taken within layers of zooplankton near whales was very high when compared to the mean for other areas. Thus, not only was the zooplankton biomass much higher near whales than elsewhere, but the nutritive value of the zooplankton was also much higher. Whales that fed in the dense concentrations of zooplankton that we sampled would maximize their return on feeding effort.

Lipid Content

The lipid content of zooplankton collected during this study is shown in Table 21. Copepods, euphausiids and amphipods had the highest lipid content and hydrozoans and pteropods the lowest. Of the four copepods studied,

Table 20. Mean wet weight, dry weight and caloric content of zooplankton collected in various situations in the Southeastern Beaufort Sea in 1986. For each tow type, samples taken within 1 km of whales observed from the ship are not included in the other groupings. Caloric content per unit dry weight and wet weight is also shown.

	Wet Weight mg/m^3 mean ± s.d.		Dry Weight mg/m^3 mean ± s.d.		Cal/m^3 mean ± s.d.		Dry Weight as a Percent of Wet Weight mean ± s.d.		Cal/g Dry Weight mean ± s.d.		Cal/g Wet Weight mean ± s.d.		Sample Size
Water Column (Oblique Tows)													
Whales <1 km from ship	532	175	95	33	467	170	18	0	4923	69	871	30	4
Yukon Coast	105	49	17	9	79	42	16	2	4400	648	717	176	13
Industrialized Zone	142	70	24	12	108	62	16	1	4443	522	732	136	20
Tuktoyaktuk Pen.	174	89	27	14	117	66	15	2	4264	427	652	125	9
Surface Tows													
Whales <1 km from ship	100	167	18	30	90	152	16	2	4471	594	736	187	4
Intense Plume	6	-	1	-	6	-	19	-	4551	-	847	-	1
Diffuse Plume	9	17	1	2	3	6	13	2	3274	957	448	205	31
Diffuse Plume/Arctic Water	5	5	1	1	2	2	14	4	2456	1741	379	348	5
Arctic Water	3	3	0	0	2	1	14	2	3654	898	526	203	11
Below Surface													
Within Layers[a]													
Whales <1 km from ship	672	489	118	90	577	452	17	1	4770	285	808	112	7
Diffuse Plume	35	13	5	3	21	15	14	2	3847	844	565	225	3
Arctic Water	114	120	19	21	81	99	15	2	3950	734	608	189	27
Diffuse/Arctic	104	69	16	13	68	66	15	2	3952	832	596	212	11
Outside Layers													
Whales <1 km from ship	273	-	44	-	200	-	16	-	4533	-	733	-	1
Diffuse Plume	8	-	1	-	4	-	13	-	3725	-	493	-	1
Arctic Water	74	41	12	7	52	36	15	2	4197	704	657	173	19
Diffuse/Arctic	9	11	1	2	6	7	14	0	4284	259	621	41	2

[a] Within layers of zooplankton that were evident on the echosounder.

Table 21. Lipid content of various species and life stages of zooplankters collected in the Southeastern Beaufort Sea in late August and early September 1986. Lipid is expressed as a percent of dry weight. The various lipid fractions are expressed as a percentage of total lipid. Lipid content for each taxonomic group and species was obtained by pooling data for species and/or life stages in that group.

	Lipid as % of Dry Weight		Percent of Total Lipid										
			% Wax Esters		% Tri-glycerides		% Fatty Acids		% Cholesterol		% Phospho-lipid		Sample Size
	Mean	± sd	Mean	± sd	Mean	± sd	Mean	± sd	Mean	± sd	Mean	± sd	
Onisimus spp.	31.3	3.4	27.6	8.9	54.4	9.3	4.6	1.5	5.4	2.9	9.7	4.6	3
Parathemisto libellula	22.8	10.7	40.7	10.3	33.7	12.6	5.2	1.8	5.5	3.1	14.9	14.2	7
Calanus glacialis IV	22.6	11.1	81.0	3.5	4.2	1.2	4.7	1.7	23.2	35.3	13.0	10.8	7
Calanus glacialis V	23.5	18.8	52.5	36.8	12.4	14.0	6.7	2.5	8.1	2.8	25.5	21.8	6
Calanus glacialis F	29.7	16.2	71.6	23.3	4.7	1.7	4.8	1.3	5.0	4.2	16.0	18.3	7
Calanus hyperboreus IV	33.6	5.0	47.6	36.8	17.0	15.8	7.4	7.3	7.7	4.9	23.5	20.6	7
Calanus hyperboreus V	37.5	19.4	64.0	32.4	9.5	12.0	6.6	3.4	9.1	8.8	17.0	16.9	7
Calanus hyperboreus F	33.6	16.3	76.1	21.0	15.1	27.1	3.5	1.3	6.7	0.6	19.1	21.2	7
Euchaeta glacialis V	33.8	19.6	63.9	21.6	9.3	7.7	6.2	2.4	5.4	0.7	17.8	12.1	4
Euchaeta glacialis F	13.6	15.3	58.4	28.3	10.3	0.5	7.5	4.5	8.2	0.0	19.7	18.4	2
Limnocalanus macrurus F	59.3	22.2	57.2	39.4	5.6	0.2	5.4	2.3	2.1	0.0	30.7	38.4	2
Limnocalanus macrurus M	28.4	12.7	58.9	19.4	4.8	1.9	5.9	2.5	6.7	4.0	23.7	15.7	3
Decapod juveniles 15 mm	19.3	15.2	21.6	13.8	9.9	4.6	8.1	3.1	9.6	3.6	50.7	11.7	7
Thysanoessa raschii	25.0	11.3	37.5	32.3	21.4	12.9	6.0	3.5	5.3	3.3	29.9	14.5	7
Boreogadus saida	15.0	4.3	31.9	37.1	8.8	5.2	9.2	4.4	15.3	2.9	39.1	23.1	7
Liparis spp.	38.4	22.2	40.0	22.0	22.6	12.6	6.6	4.2	7.7	6.0	42.3	41.2	4
Stichaeidae YOY	10.0	12.0	33.6	29.6	16.1	19.2	10.8	5.8	14.9	6.1	34.2	18.9	7
Aeginopsis laurenti	9.2	5.0	33.9	15.6	6.8	2.8	8.5	2.3	10.7	5.6	40.1	17.5	7
Aglantha digitale	3.8	5.2	49.4	23.5	5.6	3.4	15.8	12.8	9.8	8.6	24.3	18.4	5
Halitholus cirratus	7.3	5.6	43.9	31.3	8.3	6.9	6.3	2.6	11.8	6.0	32.6	22.6	7
Mysis litoralis 12 mm	9.9	8.5	37.2	30.1	5.2	1.9	24.8	20.1	11.2	5.1	29.8	18.4	6
Mysis litoralis 25 mm	15.9	8.3	16.9	20.6	42.2	18.0	9.7	3.5	10.8	5.3	21.9	11.1	7
Spiratella helicina	9.4	7.2	25.4	31.6	11.3	6.3	21.1	11.4	8.8	2.7	36.2	20.0	7
Sagitta elegans	18.5	11.4	30.9	29.7	5.1	2.1	12.4	5.6	7.2	3.8	47.3	23.6	6
Beroe cucumis	30.2	28.2	23.7	11.7	5.7	0.8	10.4	2.2	11.4	3.5	59.2	25.4	6
Mertensia ovum	11.0	3.8	44.8	21.3	5.7	1.9	6.2	2.7	6.0	2.8	38.2	18.9	7
Life Stages Pooled													
Calanus glacialis	25.1	14.9	68.5	26.5	7.0	8.4	5.3	1.9	11.4	18.8	17.8	17.2	20
Calanus hyperboreus	34.9	14.3	61.9	31.9	14.0	17.7	5.9	4.9	8.1	5.9	19.9	18.8	21
Euchaeta glacialis	27.1	19.6	62.1	21.2	9.6	6.0	6.6	2.8	6.4	1.7	18.4	12.5	6
Limnocalanus macrurus	40.8	22.1	58.2	24.0	5.1	1.4	5.7	2.1	5.5	4.0	26.5	22.5	5
Decapod juveniles	19.3	15.2	21.6	13.8	9.9	4.6	8.1	3.1	9.6	3.6	50.7	11.7	7
Mysis litoralis	12.9	8.7	27.1	26.9	25.1	23.0	17.3	15.9	11.0	4.9	25.5	14.8	13
Copepods (all)	30.9	16.4	64.1	27.5	9.7	12.5	5.8	3.5	8.7	11.9	19.5	17.6	52
< 1.8 mm	40.8	22.1	58.2	24	5.1	1.4	5.7	2.1	5.5	4	26.5	22.5	5
1.8 – 4 mm	27.4	13.5	62.9	30.3	9.7	11.4	5.9	4.1	10.3	15.9	19.3	17.9	27
> 4 mm	33.0	18.0	67.2	25.2	11.2	15.7	5.6	2.9	7.7	5.6	18.2	16.5	20
Euphausiids	25.0	11.3	37.5	32.3	21.4	12.9	6.0	3.5	5.3	3.3	29.9	14.5	7
Mysids	12.9	8.7	27.1	26.9	25.1	23.0	17.3	15.9	11.0	4.9	25.5	14.8	13
Amphipods	25.4	9.8	36.7	11.3	39.9	15.1	5.0	1.6	5.5	2.9	13.3	12.0	10
Decapods	19.3	15.2	21.6	13.8	9.9	4.6	8.1	3.1	9.6	3.6	50.7	11.7	7
Fish larvae	18.3	16.5	34.0	30.2	14.1	13.6	9.2	4.8	13.4	5.6	37.9	25.0	18
Pteropods	9.4	7.2	25.4	31.6	11.3	6.3	21.1	11.4	8.8	2.7	36.2	20.0	7
Chaetognaths	18.5	11.4	30.9	29.7	5.1	2.1	12.4	5.6	7.2	3.8	47.3	23.6	6
Hydrozoans	6.9	5.5	42.0	24.0	7.0	4.5	9.9	8.0	10.8	6.4	33.2	19.7	19
Ctenophores	19.9	20.9	36.0	20.4	5.7	1.5	8.0	3.2	8.2	4.0	47.9	23.8	13

In our samples, adult females of Calanus glacialis, and especially Limnocalanus macrurus, had high lipid content relative to other life stages.

Triglycerides and fatty acids in zooplankton resemble those in their diet and are incorporated directly from phytoplankton. These compounds are quickly broken down and their presence indicates active feeding (Raymont 1983). Wax esters are synthesized from dietary fats and are the primary long-term storage medium (Parsons et al. 1977). Copepods from high latitudes must store energy for the winter period when phytoplankton is scarce, and are characterized by high levels of wax esters (Clarke et al. 1987). Phospholipids are important components in biological membranes. They are conservative, and largely unaffected by diet (Raymont 1983).

Copepods had the highest wax ester content of any of the zooplankters that were examined. Because lipid and wax ester content of Arctic copepods peaks in August and September (Lee 1974), these values probably represent maximal values for the year.

Wax ester content of predators (Chaetognaths, Hydrozoans, Ctenophores) was lower than that of herbivores (Table 21). These differences are especially notable when lipid fractions are compared as a percentage of dry weight:

	% of Dry Weight				
	Wax esters	Fatty acids	Trigly-cerids	Chol-esterol	Phospho-lipid
Copepods	19.8	1.8	3.0	2.7	6.0
Euphausiids	9.4	1.5	5.4	1.3	7.5
Mysids	3.5	2.2	3.2	1.4	3.3
Chaetognaths	5.7	2.3	0.9	1.3	8.8
Hydrozoan	2.9	0.7	0.5	0.7	2.3
Ctenophores	7.2	1.6	1.1	1.6	9.5

In the absence of phytoplankton, euphausiids are carnivorous on zooplankton (Oman 1984) and Mysis litoralis can consume detritus (Schneider and Koch 1979). All of these animals can feed throughout the year and would not need the high wax ester content shown by copepods.

The presence of fatty acids and triglycerides in all animals indicates that they were actively feeding in late August and early September.

Limnocalanus macrurus had the highest lipid content of any zooplankter that we examined. This species probably forms the primary food source of bowheads feeding in nearshore waters (Bradstreet and Fissel 1986; Griffiths et al. 1987; this study). Its high lipid content would further enhance the attractiveness of nearshore areas to feeding bowheads because bowheads probably use this lipid to lay down fat stores for the winter.

There was a weak positive correlation between lipid content and caloric content of copepods ($r = 0.32$, $0.05>p>0.01$, $df = 49$). However, lipid content of Limnocalanus macrurus, the dominant small copepod, was higher than that of large copepods even though caloric content of small copepods was lower than that of large copepods (Table 21 vs. 18). The relationship between lipid content and caloric content of copepods was not very consistent. We did not examine protein content of zooplankton. Protein also contributes to caloric content and differences in protein content would have affected caloric content.

ACOUSTIC BIOMASS VS. NET BIOMASS

Hydroacoustic surveys can potentially provide data on zooplankton biomass at far more locations and depths than can be sampled with traditional net sampling methods. However, before the hydroacoustic data can be interpreted, it is necessary to establish the relationship of the hydroacoustic results to the zooplankton biomass as estimated with traditional net sampling. This was done by comparing the zooplankton biomass with acoustic volume scattering recorded at corresponding tow depths and stations ($n = 62$). These data, along with physical variables recorded with the tows (Table 12), were analyzed with correlation and stepwise multiple regression techniques to determine the relationships among net biomass, acoustic volume scattering, and physical variables that might affect biomass or acoustic volume scattering (Tables 22, 23). Sample sizes in these analyses were lower than those in similar analyses described earlier (Tables 13, 14) because matched hydroacoustic data were not available for each horizontal tow.

Volume scattering was only weakly correlated with zooplankton biomass ($r = 0.31$, $p<0.05$, Table 22) and was not a significant predictor of zooplankton biomass after other variables were taken into account in a stepwise multiple regression analysis (Table 23). After water density, water temperature, and transmissivity were taken into account, volume scattering did not show a significant partial correlation with zooplankton biomass (Table 23).

In some instances, turbidity was very high in nearshore waters. A layer of high turbidity could have caused hydroacoustic return that was not due to zooplankton. This might have obscured the correlation between volume scatter and biomass. Hence, the multiple regression analysis was rerun considering all samples with a transmissivity >54%. In this analysis, only volume scattering was a significant prediction of biomass (Table 23). However, volume scattering accounted for only 19% of the variance in zooplankton biomass (i.e. $R^2 = 0.19$). Although volume scattering was a significant predictor of zooplankton biomass in areas where transmissivity was >54%, the low R^2 value precluded the estimation of zooplankton biomass from volume scattering.

The better multiple correlation when high turbidity cases were omitted shows that high turbidity interfered with the estimation of zooplankton biomass from acoustic data. However turbidity may not have been the only factor that caused the low correlation between acoustic and zooplankton data. The lack of correspondence between the zooplankton biomass as recorded with net tows and the corresponding acoustic data could be due to one or a combination of three factors: (1) many of the zooplankters were too small to be effectively sampled with the echosounder used in this study, (2) acoustic returns from fish confounded the data, and (3) there was interference from turbidity layers and/or pycnoclines.

Table 22. Correlations of volume scattering and total zooplankton biomass with physical variables for (a) all samples, and (b) samples with a transmissivity >54%. Significance levels for these Pearson product-moment correlation coefficients are shown by asterisks (* P<0.05; ** P<0.01; *** P<0.001). Physical variables are described in Table 13.

	All Samples		Transmissivity >54%	
	Volume Scattering	Total Biomass	Volume Scattering	Total Biomass
Station Depth	-0.32 *	-0.36 **	-0.33 *	-0.18
Tow Depth	0.51 ***	0.09	0.53 ***	0.31 *
Temperature	-0.31 *	-0.17	-0.32 *	-0.24
Temp. Difference	-0.08	-0.05	-0.15	0.01
Transmissivity	-0.05	-0.61 ***	-0.05	-0.23
Trans. Difference	0.15	0.43 ***	0.17	0.29 *
Density	0.48 ***	0.39 **	0.50 ***	0.42 **
Density Difference	-0.13	-0.14	-0.19	-0.06
Density Diff. + 2 m	-0.12	-0.10	-0.20	-0.10
Density Diff. - 2 m	-0.09	-0.18	-0.12	0.00
Volume Scattering	-	0.31 *	-	0.45 ***
Total Biomass	0.31 *	-	0.45 ***	-
Sample Size	62	62	51	51

Table 23. Multiple regression analysis[a] of the total biomass of zooplankton in horizontal bongo tows in relation to physical variables for all samples and samples with a transmissivity >54%. Nominal significance levels are shown by asterisks (* $P<0.05$; ** $P<0.01$; *** $P<0.001$). Variables denoted by '-' were not of significant value as predictors of biomass ($P>0.05$) and were excluded from the equation. Physical variables are described in Table 13.

	All samples	Transmissivity >54%
Constant (Y-intercept)	-0.699	-11.867
Volume Scattering	-	0.116 ***
Station Depth	-	-
Tow Depth	-	-
Temperature	0.117 *	-
Temp. Difference	-	-
Transmissivity	-0.015 ***	-
Trans. Difference	-	-
Density	0.154 ***	-
Density Difference	-	-
Density Diff. + 2 m	-	-
Density Diff. - 2 m	-	-
Multiple R	0.76 ***	0.45 ***
% of variance explained	55	19
SE of estimate	0.34	0.36
Sample Size	62	51

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[a] The regression coefficient of each variable that entered the equation is shown along with the constant (Y-intercept) and statistics describing the fit of the equation. Biomass transformed to $\log(\text{mg/m}^3)$ prior to analysis.

Limnocalanus macrurus was the dominant zooplankter in bongo net samples. Adults of this species are less than 2 mm in length. Because of their small size they may not have been adequately sampled with the 200 kHz echosounder. When target dimensions are less than the wavelength of the sound pulses, as was the case here, echo return depends very strongly on target size. The effective radius of an adult *Calanus hyperboreus* is about four times larger than that of an adult *Limnocalanus* and the acoustic backscatter from *C. hyperboreus* is expected to be about three orders of magnitude larger than that from *Limnocalanus*. Thus, *Limnocalanus* was probably underrepresented, relative to larger zooplankters, in the hydroacoustic data. However, it should be noted that Griffiths et al. (1987) found good correspondence between high biomasses of *Limnocalanus* in net samples and high volume scattering at 200 kHz. Thus, it is doubtful that the small size of *Limnocalanus* was the main reason for the poor correlation in the present study.

In the eastern Alaskan Beaufort Sea, Griffiths et al. (1987) recorded numerous fish on their echosounder in early-mid September of 1986. These fish gave a very strong acoustic return but were rarely caught in zooplankton nets; thus there was no correlation between net zooplankton biomass and raw hydroacoustic data. When the returns from fish were electronically removed from the acoustic data, there was a good correlation between acoustic biomass and zooplankton biomass. We do not know if fish were equally abundant in the Canadian Beaufort Sea in late August-early September of 1986. If so, acoustic returns from fish could have caused the observed lack of correlation between acoustic biomass and net biomass. The method of collection of the hydroacoustic data during this study did not allow later re-processing to remove strong echoes from fish.

High acoustic returns also can be caused by density differences between two water masses. Strong acoustic returns were recorded from pycnoclines in the eastern Alaskan Beaufort Sea in 1985 and 1986 (Griffiths et al. 1987). A strong pycnocline was also found in the present study area. However, the correlation between volume scattering and zooplankton biomass was not improved when samples associated with large density differences were excluded from the analysis. As previously mentioned, turbidity interfered with the estimation of zooplankton biomass from the acoustic data. Layers of high turbidity could have given high acoustic returns in the absence of high zooplankton standing crop.

Thus, high acoustic returns in the absence of concentrations of zooplankton could have been caused by density interfaces, differences in turbidity between water masses, or fish. Low returns could have been recorded in the presence of concentrations of zooplankton if the zooplankters were very small.

Whatever the specific explanation, the acoustic data collected in this study were not representative of zooplankton standing crop; they are not considered further in this report.

DISCUSSION

Relevance to BEMP Hypotheses

Use of the area of industrial activity north of the Mackenzie Delta by bowhead whales has declined since 1980 (Richardson et al. 1985a, 1987a; Norton and Harwood 1986; Harwood and Norton 1986). Two hypotheses were advanced by Richardson et al. (1983) and elaborated during BEMP--the Beaufort Environmental Monitoring Project (e.g., ESL et al. 1986)--to explain this decline: (1) Bowheads are now avoiding the industrial zone as a long term response to noise and disturbance, and (2) bowhead distribution varies annually in response to natural variation in physical and biological oceanographic features that affect their food supply. These hypotheses are not mutually exclusive; natural variations in food and disturbance responses could occur simultaneously. Thus far it has not been possible to confirm or refute the avoidance hypothesis in the absence of

1. pre-development distributional data,
2. experimental control over the amounts of annual industrial activity,
3. much information about year-to-year variations in food availability, or
4. data on the way in which bowhead whales respond to natural variation in the distribution of their food.

It is recognized that no one study of pre-defined duration can be designed that will, with certainty, determine the cause(s) of the year-to-year variability in the summer distribution of bowheads (ESL et al. 1986). However, future trends in distribution may help resolve the issue. The amount of industrial activity has declined at least temporarily in 1985-86. This may provide an opportunity to assess the distributional responses of bowheads--a "pseudo experiment". However, it is not certain how complete and how prolonged the decline in industrial activity would have to be before bowheads would be expected to return, assuming that the exclusion hypothesis has been responsible for some of the distributional changes over the past decade.

Questions 3 and 4 from the above list, relating primarily to variable food, are somewhat easier to study than are questions 1 and 2. This study in 1986 and its predecessor in 1985 (Bradstreet and Fissel 1986) were designed to provide the first detailed information on the natural variability in the distribution of the zooplankton that is preyed upon by bowhead whales in the southeastern Beaufort Sea, and about the responses of bowheads to that variability. It was expected that these studies would provide a better understanding of the overall importance of the southeastern Beaufort Sea in the annual energy budget of bowhead whales. Thus the results of the 1985 and 1986 food availability studies were expected to contribute to our understanding of factors controlling bowhead distribution in the Beaufort Sea, even though they could not resolve the overall issue.

The preceding sections of this report presented the results of studies conducted in 1986. The following discussion integrates these results with those from our related 1985 work (Bradstreet and Fissel 1986) and those obtained during a companion study of bowhead feeding ecology in the eastern Alaskan Beaufort Sea in 1985 and 1986 (Richardson [ed.] 1987). We first compare the amount of potential food available to bowhead whales in various regions of the Beaufort Sea and compare the species composition of the plankton with known foods of bowhead whales. The next section discusses regional and annual differences in the physical oceanographic regime in terms of its effects on availability of prey for bowheads. The third section deals with the characteristics of bowhead feeding areas. This is followed by a discussion of the energetic requirements of bowhead whales and an assessment of the energetic importance of the southeastern Beaufort Sea to bowheads at the population level. We conclude by evaluating the above hypotheses in the light of the new data.

Distribution of Zooplankton

Bowheads and other right whales strain zooplankton from the water (Pivorunas 1979). In order to meet theoretical energetic requirements, bowheads must feed in areas where the biomass of zooplankton is higher than the average biomass in the water column (Thomson 1987b). Results of this study and those of Griffiths and Buchanan (1982), Bradstreet and Fissel (1986) and Griffiths et al. (1987) show that bowheads do feed in areas with a higher than average biomass of zooplankton. Species composition of the zooplankton prey appears to vary widely. Bowheads feed mainly on crustacean prey, including copepods, euphausiids, mysids and even benthic amphipods (Lowry and Frost 1984; Lowry et al. 1987). One of the objectives of this and related studies was to describe the overall distribution and abundance of zooplankton as related to bowhead feeding.

Zooplankton biomass data for the Beaufort Sea are available from Griffiths and Buchanan (1982) who sampled in the area north of Richards Island (Mackenzie Delta) in 1980 and 1981 and off the Yukon coast in 1980; Bradstreet and Fissel (1986) who sampled off the Yukon coast in September 1985; and Griffiths et al. (1987) who sampled in the eastern Alaskan Beaufort Sea in 1985 and 1986 and across the whole Alaskan Beaufort Sea in October 1986. The best sources of data for general comparisons of zooplankton standing crop are oblique or vertical tows because they average the biomass in the water column. Griffiths and Buchanan (1982) sampled only with horizontal tows in 1981, so their 1981 data are not considered here.

Mean zooplankton biomass was remarkably similar in all areas of the Beaufort Sea that have been sampled (Table 24). The only sampling program that gave an unusually high mean biomass was the 1980 sampling off Richards Island. However, gelatinous zooplankton dominated in these 1980 samples, and biomass of copepods was comparable to that of other areas and years. The other estimates of mean biomass from eight different times and areas ranged

Table 24. Mean biomass of zooplankton (mg/m^3) collected in the top 50 m in various parts of the Beaufort Sea.

	Canadian Beaufort Sea						Alaskan Beaufort Sea		
	Yukon Coast			Industrial Zone		Tuk Pen	Eastern		All
	1980[a]	1985[b]	1986[c]	1980[a]	1986[c]	1986[c]	1985[d]	1986[d]	1986[d,e]
Total biomass	166	211	173	632	153	210	224	177	175
Limnocalanus macrurus	20	144	67	<1	<1	<1	43	59	e
Calanus hyperboreus	31	15	27	128	74	97	80	17	e
Calanus glacialis	1	13	23	11	21	26	25	52	e
Copepoda	64	181	121	141	99	126	168	130	21
Mysidacea	22	8	7	6	7	5	5	1	<1
Euphasiacea	0	2	11	<1	2	<1	8	<1	21
Hydrozoa + Ctenophores	64	7	18	471	23	35	22	15	112
Chaetognatha	3	4	6	6	5	17	6	4	13
Sample Size	24	16	15	48	21	10	10	18	25

[a] Griffiths and Buchanan (1982).
[b] Bradstreet and Fissel (1986).
[c] This Study.
[d] Griffiths et al. (1987).
[e] October 1986, Barrow to Demarcation Bay over depths 50 m to 2000 m. Samples not identified to specific level.

from 166 to 240 mg/m^3. Given the variability of zooplankton in the ocean, this is a very small range in mean biomass. However, the samples were all taken from August to mid October, and sample-to-sample variability within the geographic regions and periods shown in Table 24 has been averaged.

There are no data on bowhead stomach contents for the Canadian Beaufort Sea. However, bowheads are harvested in early autumn (mainly September) about 200 km west of our study area, near Kaktovik, Alaska. In the following section we compare the species composition of the zooplankton in the study area with the species composition of zooplankton in the stomachs of bowheads harvested near Kaktovik.

Copepods

Copepods--mainly *Limnocalanus macrurus*, *Calanus hyperboreus* and *C. glacialis*--were the dominant taxa in samples collected in the Beaufort Sea (Table 24). Copepods were more abundant in areas where bowheads were feeding than in areas where bowheads were absent; this was true in all situations when zooplankton was sampled near and far from bowheads: off the Yukon coast in 1985 and 1986, off the Tuktoyaktuk Peninsula in 1986, off the Kongakut Delta in early September 1986 and off Richards Island during 1980-81 (Griffiths and Buchanan 1982; Bradstreet and Fissel 1986, Griffiths et al. 1987; this study). Copepods were the major food group in the stomachs of 7 of 11 bowheads taken near Kaktovik (Lowry and Frost 1984; Lowry et al. 1987). Copepods are also known to be the predominant food for balaenid (= right) whales in other oceans (e.g., Nemoto 1959; Nemoto and Kawamura 1977; Mayo et al. 1985).

The small copepod *Limnocalanus macrurus* was the dominant zooplankter near the Yukon coast in 1985 and 1986; however, its mean abundance was much reduced in 1986 (Table 24). In the adjacent eastern Alaskan Beaufort Sea, the reverse occurred; *L. macrurus* was more abundant in 1986 than 1985. The water masses in which *L. macrurus* concentrated covered a much greater portion of the continental shelf of the eastern Alaskan Beaufort Sea in 1986 than in 1985.

Limnocalanus macrurus was the dominant copepod in plankton tows taken near feeding bowheads off the Yukon coast in 1985 and 1986 and in nearshore areas of the eastern Alaskan Beaufort Sea in 1986 (Bradstreet and Fissel 1986; Griffiths et al. 1987; this study). Neither this species nor other small copepods had been observed in bowhead stomachs before 1986. However Lowry et al. (1987) recovered large numbers of *L. macrurus* and other small copepods from the stomach of a bowhead taken near Kaktovik in the fall of 1986. Its absence in bowhead stomachs in previous years may have reflected its low abundance in the areas where these whales had been feeding. The general distribution and abundance of *L. macrurus* in the Beaufort Sea is apparently quite variable from year to year (Horner 1981; Griffiths et al. 1987; this study).

Little is known about the ecology and life history of *L. macrurus* in the Beaufort Sea. Bradstreet and Fissel (1986) and Griffiths at al. (1987) believe that it has a one year life history in Arctic marine waters. However this conclusion is based on marine sampling conducted over very short periods in late August and September, and on results obtained in fresh water. Previous work on Arctic zooplankton indicated that *L. macrurus* was mainly associated with the presence of freshened waters (Johnson 1956; Grainger and Grohe 1975). However, our results and those of Johnson (1956) and of Griffiths et al. (1987) confirm that it occurs commonly in nearshore areas, but the results also show that it can tolerate and apparently thrives in cold saline water. In fact, during both years of this study, maximum abundance of *L. macrurus* was recorded in nearshore areas with Arctic water rather than in estuarine water influenced by the Mackenzie River (Table 9, Bradstreet and Fissel 1986). This species is very important to bowheads that feed in nearshore waters of the Beaufort Sea.

Use by bowheads of nearshore areas off the Yukon coast and in the eastern Alaskan Beaufort Sea is quite variable (Fraker and Bockstoce 1980; Richardson et al. 1987a,b). Most bowheads that fed in these nearshore areas in the late summers of 1983-86 were small subadult whales. The variable abundance of *L. macrurus*, whether due to differences in distribution or life history, could be one cause of the variable use of nearshore areas by subadult bowhead whales.

However, this cannot yet be confirmed because detailed data on zooplankton along the Yukon coast are available only for 1985-86.

Calanus hyperboreus and C. glacialis are generally the dominant copepods in Arctic waters (Grainger 1965, 1975) and account for most of the biomass of copepods recovered from the stomachs of bowhead whales (Lowry and Frost 1984; Carroll et al. 1987). They were the dominant copepods in samples taken near feeding whales off Richards Island in the Canadian Beaufort Sea in 1980 and 1981 (Griffiths and Buchanan 1982) and off the Tuktoyaktuk Peninsula during this study (Table 17). These two species, along with euphausiids, may be the major prey of bowheads that feed in offshore waters and along the migration route. These two species were the dominant copepods at depths >40 m off the Yukon coast in 1986, off Richards Island in 1980, 1981 and 1986, and off the Tuktoyaktuk Peninsula in 1986 (Tables 5, 24).

Pseudocalanus spp. was uncommon off the Yukon coast in 1985 (Bradstreet and Fissel 1986) and in 1986 (Table 5). It was also rare in the eastern Alaskan Beaufort Sea in 1985 and 1986. However, Griffiths and Buchanan (1982) found Pseudocalanus spp. to be quite common at all of their sampling locations in the Canadian Beaufort Sea in 1980-81. Pseudocalanus spp. was found in only 1 of 11 stomachs of bowheads harvested in the Kaktovik area (Lowry and Frost 1984; Lowry et al. 1987). Pseudocalanus spp. are about the same size as Limnocalanus macrurus and could be consumed by bowheads.

Euphausiids

Euphausiids formed a large proportion of the stomach contents of eight bowheads taken near Kaktovik (31% of volume, Lowry and Frost 1984). Four whale stomachs from Kaktovik contained significant amounts of euphausiids; three of those were taken in one year (Lowry and Frost 1984; Lowry et al. 1987). In this study, mean biomass of euphausiids was 16 to 20 times higher in horizontal and oblique tows taken near whales than in tows taken where no whales were seen from the ship (Table 16). However, even in these circumstances, euphausiids did not form a large percentage of total zooplankton biomass (Table 6). Euphausiids were more abundant off the Yukon coast in 1986 (6% of biomass in oblique tows) than in 1985 (1% of biomass in oblique tows, Bradstreet and Fissel 1986). In the Eastern Alaskan Beaufort Sea, euphausiids were far less abundant in September and October of 1986 than in September 1985. The relative abundance of euphausiids in bowhead stomachs and in the plankton appears to be quite variable from year to year.

It is possible that euphausiids are more abundant in the western than the eastern Beaufort Sea, and that bowhead whales take proportionately more euphausiids in the western area. In October 1986, euphausiids were quite abundant in the western Beaufort Sea, off Barrow (Griffiths et al. 1987). The two whales harvested at Barrow in fall whose stomach contents were examined both contained mainly euphausiids (Lowry et al. 1978; Lowry and Frost 1984). Horner (1981) also found euphausiids to be abundant off Barrow and especially off the Harrison Bay region in 1976. In October 1986, abundance of euphausiids decreased from west to east across the Alaskan Beaufort Sea (Griffiths et al. 1987). This trend appeared to continue in the southeastern Beaufort Sea. Biomass of euphausiids was apparently higher off the Yukon coast and Mackenzie Delta than off the eastern Tuktoyaktuk Peninsula, where none was found (Table 5).

Euphausiids are often found in swarms. They also can move rapidly, and are well known as being able to avoid capture by many types of sampling gear. Even at times when they are common they may be missed or underestimated because of their patchy distribution and ability to avoid sampling nets. The abundance of euphausiids on the North Aleutian Shelf varies from season to season, year to year, and location to location, and is associated with intrusions of oceanic water onto the shelf (Thomson 1987a). In that area, euphausiids tended to form dense swarms in mid water or just above the bottom. In southeastern Alaska, euphausiids often concentrate into very dense and localized swarms, and humpback whales concentrate their feeding on these swarms (Dolphin 1987). The physical circumstances associated with a high abundance of euphausiids in the Beaufort Sea are unknown.

Mysids

One of 11 whales harvested at Kaktovik had been feeding mainly on mysids. Mysids are common in nearshore waters of the Beaufort Sea (Broad et al. 1980;

Griffiths and Dillinger 1981; Horner 1981; Jewett et al. 1984; Bradstreet and Fissel 1986; Table 5). Mysids often concentrate near the bottom, where they may be missed or underestimated by standard zooplankton tows. Mysids can form dense shoals along the coast (Thomson et al. 1978) and the presence of dense shoals might provide good foraging opportunities for a whale. Such a shoal may have been present at an interface between turbid Mackenzie River water and clear oceanic water that was sampled during this study. Mysids were the dominant taxon on the clear side of the front (Table 10) and maximum biomass in a horizontal tow taken at this front was 139 mg/m^3. Bowheads were observed in this general area during aerial surveys (Fig. 39).

Zooplankton vs. Diet

There are some similarities and some differences between the species compositions of the zooplankton (a) in the southeastern Beaufort Sea vs. (b) in the stomach contents of bowheads harvested at Kaktovik, NE Alaska. Limnocalanus macrurus probably forms the major food source of bowheads that feed in nearshore areas along the Yukon coast and close to shore in the eastern Alaskan Beaufort Sea. It has been recorded from the stomach of only one bowhead whale; however, this is probably a reflection of the species composition of the plankton in the areas where various bowheads were harvested. Bowheads also find and exploit concentrations of Calanus spp. Calanus spp. were the dominant species in offshore waters of the Beaufort Sea, and dominated the zooplankton at whale feeding locations off the Mackenzie Delta and Tuktoyaktuk Peninsula. Stomach contents show that bowheads sometimes feed in concentrations of euphausiids, at least off northern Alaska. In this study, euphausiids were more abundant in samples taken near whales than in samples taken where no whales were found, but apparently did not dominate the zooplankton even at the feeding locations. Mysids were concentrated at a turbidity front in Mackenzie Bay in a general area where whales were observed from the air. Both euphausiids and mysids were probably underestimated in our samples because of inevitable sampling problems.

Assuming that bowheads feed on the most abundant zooplankters present in the water column, the food of bowhead whales in the southeastern Beaufort Sea probably consists mainly of copepods with occasional meals of mysids and euphausiids. Limnocalanus macrurus was the most abundant potential prey in shallow nearshore waters, whereas Calanus spp. were the most abundant potential prey farther offshore.

Caloric and Lipid Content of Zooplankton

Caloric content of copepods sampled in late August and early September 1986 was lower than during the same period in 1985 (Table 25). Similar results were obtained in the eastern Alaskan Beaufort Sea in September of 1986 vs. 1985 (Griffiths et al. 1987). They speculate that food was less plentiful for copepods in 1986 than in 1985. Upwelling was common in their study area in 1985 but not in 1986 (Fissel et al. 1987), and resultant differences in primary production may have affected food supply for copepods. In the eastern Alaskan Beaufort Sea, surface chlorophyll a concentrations were 5 times lower in September 1986 than in September 1985. We do not know if there was any difference in food supply for zooplankton in the Canadian Beaufort Sea during 1985 and 1986; however, coastal upwelling activity was reduced off the Yukon coastline in 1986 as compared to 1985. In both years caloric content of copepods was higher in the Alaskan than Canadian Beaufort Sea. The Alaskan samples were taken slightly later in the season than were the Canadian samples and caloric content generally increases over the summer.

Caloric content of copepods from the Eastern Alaskan and Canadian Beaufort Sea in 1985 was similar to that of copepods from Frobisher Bay (6.8 to 7.7 Kcal/g, Percy and Fife 1980). Caloric content of copepods sampled in both areas in 1986 was lower and similar to values recorded in the Bering Sea and Atlantic Ocean (5 to 6.4 Kcal/g, Laurence 1976; Harris 1985).

Lipid content of copepods collected in this 1986 study was 31 ± 16% of dry weight. In 1985 lipid content of samples that contained >90% copepods was 33 to 39% of dry weight (Bradstreet and Fissel 1986, Table 24). This decrease in lipid content between years probably caused the decrease in caloric content between years, given that copepods store energy in the form of lipids and caloric content of lipid is higher than that of other components. Lipid content of copepods collected during this study was lower than values recorded by other Arctic researchers, but comparable to that of copepods from other areas:

	Lipid (% dry wt.)	Month	Region	Reference
All copepods	31%	Aug/Sep	Beaufort Sea	This Study
Calanus hyperboreus	35%	Aug/Sep	Beaufort Sea	This Study
Calanus spp.	57%	Jul/Sep	Frobisher Bay	Percy and Fife (1980)
Calanus hyperboreus	74%	Aug	Arctic Ocean	Lee (1974)
Copepods	8-45%	Summer	AntArctic Ocean	Reinhardt and Van Vleet (1986)
Copepods	18%		Subtropical Pacific	Raymont 1983

It is not certain why lipid content of Calanus hyperboreus from the southeastern Beaufort Sea is lower than that of the same species collected by Lee (1974) under ice island T3 in the Arctic Ocean. Food supply is much lower under the permanent ice where Lee sampled. On the other hand, the oceanic summer is shorter there than in our study area, and copepods may have to store more food for a longer winter. Differences in methodology may also account for some apparent differences in lipid content.

Whales, Zooplankton and Physical Oceanography

Concurrent biological and physical oceanographic sampling was conducted off the Yukon coast in 1985 and 1986, and off the Mackenzie Delta and Tuktoyaktuk Peninsula in 1986 (Bradstreet and Fissel 1986; this study). Aerial surveys for whales also were conducted during the biological and physical field work (Davis et al. 1986b; Norton and Harwood 1986; Harwood and Norton 1986; Richardson et al. 1986b, 1987b; Ford et al. in prep.). In the following sections we relate the distribution of zooplankton to the physical oceanographic regime, and then compare the distribution of whales to the distributions of zooplankton and water properties. Annual variations in the physical oceanographic regime, zooplankton distribution, and whale distribution are then discussed.

Zooplankton vs. Water Masses

The water types observed in the study area represented varying mixtures of cold saline Arctic water and fresh, warmer Mackenzie River water. Mackenzie River water occurred as two distinct water types. The intense plume was very warm, turbid and found only adjacent to the Mackenzie River delta. Diffuse plume water was a reduced mixture of Mackenzie River water with Arctic water. Diffuse plume water covered most of the surface of the study area in 1986. The diffuse plume extended to distances of 100 km from the coast and, in most areas, affected the upper 8 to 10 m of the water column. The effects of direct solar insolation were also apparent, particularly on the eastern half of the Mackenzie Shelf, where noticeably higher temperatures occurred at intermediate salinities (28-31 psu) over depths of 0 to 20 m. This warming of Arctic water appears to originate either locally or from westward advection of warmer water from the entrance to Amundsen Gulf, the location of the Cape Bathurst polynya.

A prime determinant of the distribution of zooplankton biomass in the southeastern Beaufort Sea in 1985 and 1986 was the distribution of the Mackenzie River plume. In both years, mean zooplankton biomasses in horizontal tows taken at the surface and at depth were higher in Arctic water than in diffuse plume water or mixed diffuse plume/Arctic water (Table 26). In 1986 mean biomasses in oblique tows were higher where Arctic water was present at all depths than at locations with some Mackenzie River influence (Table 26). Biomass in horizontal tows was highest in high density water (low temperature, high salinity Arctic water) and lowest in low density water (Table 14).

The relationship between the distribution of the Mackenzie River plume and zooplankton biomass may explain geographic differences in mean zooplankton biomass noted in Tables 4 and 5. Off the Yukon coast in early September 1986, zooplankton biomass was lower in offshore waters than in nearshore waters (Table 4). In that area, the influence of Mackenzie plume water was high in offshore waters, whereas Arctic water was often present even at the surface in nearshore waters (Fig. 30). The reverse occurred north of the Mackenzie Delta; mean biomass was low in the nearshore waters and increased offshore

Table 26. Mean biomass (± s.d.) of zooplankton in surface, oblique and horizontal tows taken in various water masses in the Southeastern Beaufort Sea in 1985 and 1985. For surface and oblique tows, water mass categories were those of surface water. For horizontal tows, water mass categories are those at the depth of the tow. Includes all stations on broad scale transects sampled in 1985 and 1986, but not specific whale feeding and control stations (26, 27) sampled in 1985. The percent of total biomass represented by copepods is shown. The sample size is shown in parentheses.

	Diffuse Plume			Diffuse/Arctic			Arctic Water		
Taxon/Year	Mean	± s.d.	%/n	Mean	± s.d.	%/n	Mean	± s.d.	%/n
Surface Tows									
1985 Copepods	57	146	96%	-	-	-	994	706	99%
All Zoopl.	59	147	(9)	-	-	(0)	1008	714	(9)
1986 Copepods	1[a]	1	11%	8	17	64%	69	151	96%
All Zoopl.	9[a]	16	(33)	12	17	(6)	73	154	(5)
Oblique Tows									
1985 Copepods	171	215	85%	222	352	91%	128	-	75%
All Zoopl.	202	227	(11)	243	354	(4)	170		(1)
1986 Copepods	86[a]	83	60%	132	94	60%	281	259	86%
All Zoopl.	142[a]	95	(33)	221	127	(7)	326	279	(5)
Horizontal Tows at Depth[b]									
1985 Copepods	54	97	76%	-	-	-	417	455	92%
All Zoopl.	71	103	(5)	-	-	-	462	460	(15)
1986 Copepods	10	17	28%	45	75	44%	141	299	62%
All Zoopl.	35	13	(3)	104	69	(11)	229	327	(34)

[a] Intense and diffuse plume data combined in diffuse plume column.

[b] Tows taken within distinct layers of zooplankton as shown on the echo-sounder.

(Table 5). Mackenzie plume influences were greatest in the nearshore waters north of the Delta and decreased offshore (Fig. 30). Mean biomass was highest off the eastern Tuktoyaktuk Peninsula (Table 24) where Mackenzie River influences were much reduced (Fig. 30).

Whales vs. Zooplankton and Water Masses

On a broad scale, the distribution of whales recorded during aerial surveys in 1986 (Harwood and Norton 1986, in prep.) paralleled that of zooplankton and the Mackenzie River plume. Whales were found in nearshore waters off the Yukon coast, at the interface between the turbid plume and clearer water in Mackenzie Bay, and in offshore waters off the eastern Tuktoyaktuk Peninsula. With the exception of the whales in the interface zone, Mackenzie River influences were minimal in the areas where whales were observed (Fig. 40c,d).

Although aerial surveys for bowheads were not well coordinated with the zooplankton sampling, zooplankton biomass was higher at stations in areas where whales were observed from the air than in areas where no whales were observed (Table 15). A closer relationship might have been found if aerial surveys at each station had been closer in time to the periods of zooplankton sampling. Most whales were located in areas where the surface water had Arctic or mixed Arctic/diffuse plume characteristics. Zooplankton biomass was higher in Arctic water than in water under the influence of the Mackenzie River plume.

Off the Yukon coast, local offshore winds in early September of 1986 displaced Mackenzie river water at the surface. It was apparently replaced with Arctic water from depths of 10 to 15 m. Thus Arctic water was found at the surface close to shore during our zooplankton sampling in this area, and Mackenzie River water was at the surface farther offshore. The most striking response to local winds was observed between Shingle and Kay Points. Between 3 and 8 September 1986, there was an expansion of the area with Arctic water at the surface (Fig. 40c,d). This occurred in response to intense local southwest winds, driven by orographic effects, that blew between 3 and 6 September. The Arctic water at the surface in that area probably originated

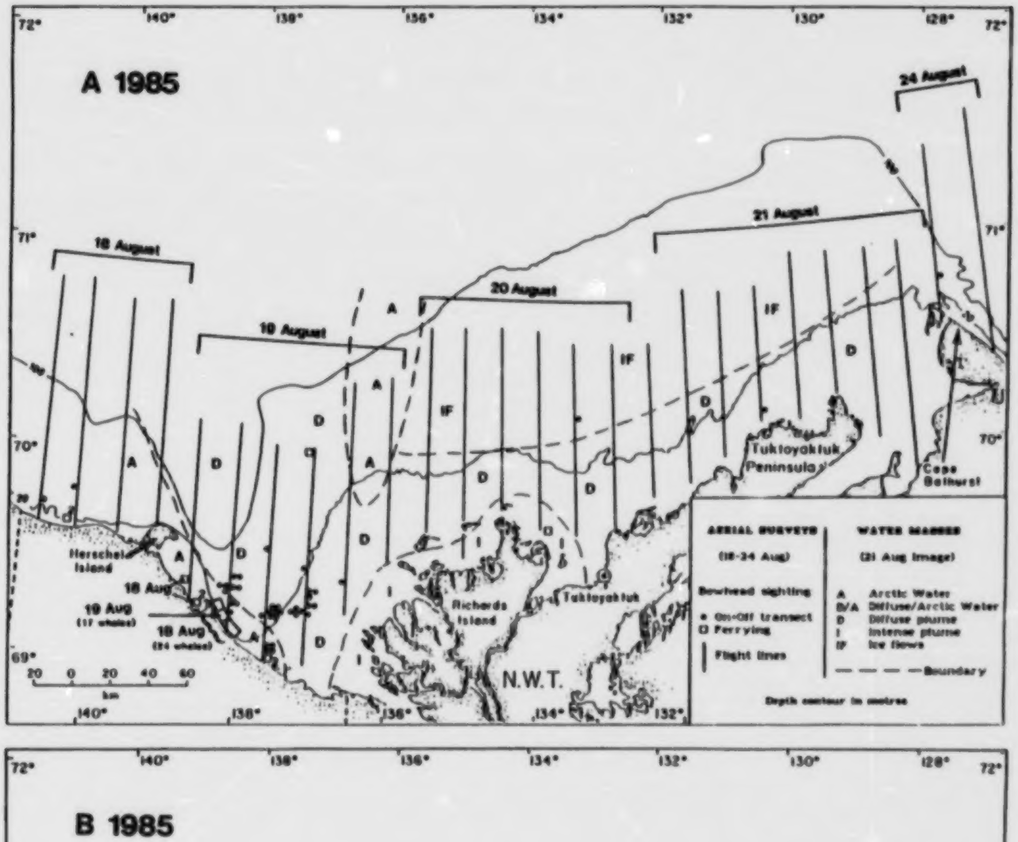
A 1985
24 August
21 August
20 August
18 August
19 August
A
D
IF
I
Tuktoyaktuk Peninsula
Cape Bathurst
Herschel Island
18 Aug
19 Aug (17 whales)
18 Aug (24 whales)
Richards Island
Tuktoyaktuk
N.W.T.
AERIAL SURVEYS
(18-24 Aug)
Bowhead sighting
• On-Off transect
☐ Ferrying
Flight lines
WATER MASSES
(21 Aug Image)
A Arctic Water
D/A Diffuse/Arctic Water
D Diffuse plume
I Intense plume
IF Ice flows
Boundary
Depth contour in metres
20 0 20 40 60
km
72°
71°
70°
69°
140°
138°
136°
134°
132°
130°
128°
B 1985
14 September
16 September
11 September
12 September
(14 whales)
11 Sept (8 whales)
(16 whales)
Yukon
AERIAL SURVEYS
(11-16 Sept)
Bowhead sighting
• On-Off transect
☐ Ferrying
Flight lines
Depth contour in metres

Figure 40. Distribution of bowheads seen during aerial surveys and boundaries of the Mackenzie River plume defined by satellite imagery that most closely corresponded in time to aerial surveys. Plume boundaries off the Delta and Tuk. Pen. in Figure 40C were defined by oceanographic sampling. From Borstad (1986); Harwood and Norton (1986, in prep.); Norton and Harwood (1986).

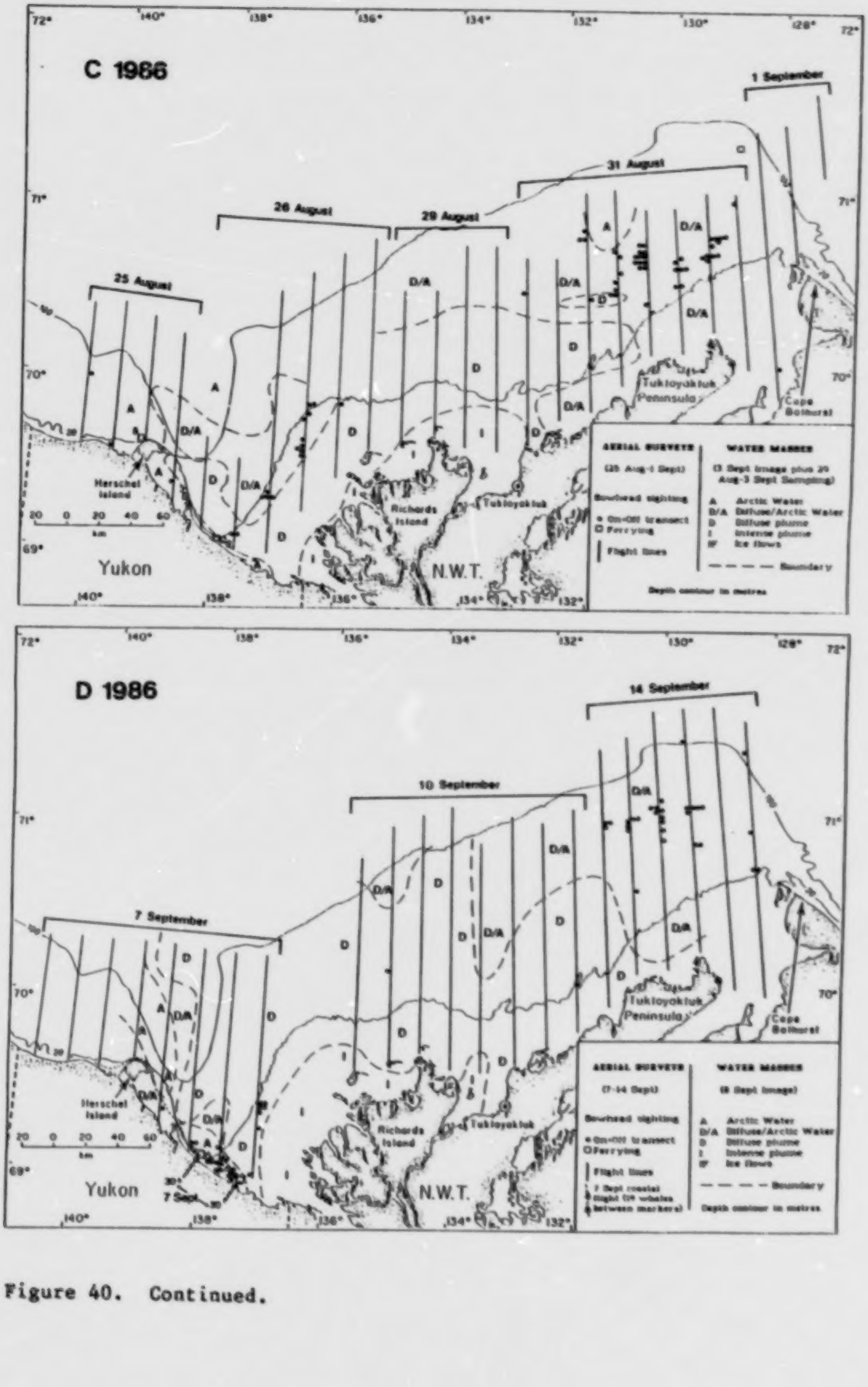
C 1986
25 August
26 August
29 August
31 August
1 September
A
D/A
D
I
Herschel Island
Richards Island
Tuktoyaktuk
Tuktoyaktuk Peninsula
Cape Bathurst
Yukon
N.W.T.
20 0 20 40 60
km
72°
71°
70°
69°
140°
138°
136°
134°
132°
130°
128°
AERIAL SURVEYS
(25 Aug-1 Sept)
Bowhead sighting
On-Off transect
Ferrying
Flight lines
WATER MASSES
(3 Sept image plus 29 Aug-3 Sept Sampling)
A Arctic Water
D/A Diffuse/Arctic Water
D Diffuse plume
I Intense plume
IF Ice flows
Boundary
Depth contour in metres
D 1986
7 September
10 September
14 September
7 Sept
30
AERIAL SURVEYS
(7-14 Sept)
Bowhead sighting
On-Off transect
Ferrying
Flight lines
7 Sept coastal flight (9 whales between markers)
WATER MASSES
(8 Sept image)
A Arctic Water
D/A Diffuse/Arctic Water
D Diffuse plume
I Intense plume
IF Ice flows
Boundary
Depth contour in metres

Figure 40. Continued.

as a combination of local upwelling, limited to depths of approximately 20 m, and possible lateral entrainment from Arctic water found farther west. The surface front at the offshore boundary of the Arctic water along this part of the Yukon coast was the most intense front that we sampled.

Similar features were observed off the Yukon coast in 1985 (Bradstreet and Fissel 1986). In 1985, the prevailing winds were easterly, which would be expected to cause classical coastal upwelling. Such upwelling caused cold Arctic water to appear at the surface. However, short periods of intense but local southwest winds did occur in 1985 as well as 1986, coinciding with a brief period of west to northwest winds elsewhere.

The occurrence of locally intense southwest winds off the Yukon coast in southern Mackenzie Bay may have important biological consequences. These winds may cause (a) local upwelling, (b) intense frontal features between upwelled Arctic water and Mackenzie River water, and (c) nutrient replenishment of surface waters from depth. Each of these phenomena could affect the distribution of zooplankton. If upwelling were continuous for an extensive period of time, primary productivity could be increased. This might cause zooplankton to aggregate in such areas. Our results indicate that southwest winds blowing off the Yukon coast are sufficient in themselves to cause coastal upwelling of Arctic water in Mackenzie Bay at times when the regional wind regime would not otherwise be favorable for upwelling. Because both easterly and southerly to westerly winds can cause upwelling along this part of the Yukon coast, conditions here may be unusually conducive to the formation of zooplankton concentrations and areas of increased productivity.

In any case, zooplankton biomass averaged considerably higher when the surface water was Arctic water rather than Mackenzie plume water (Table 26). Thus, coastal upwelling of Arctic water probably caused zooplankton biomass to be higher than if the area were under the influence of Mackenzie River water. This was probably the reason that the Yukon coast was an attractive feeding ground for bowheads in 1985, 1986 and some previous years.

Over the Mackenzie Shelf in 1986, diffuse plume waters extended far offshore--up to 110 km north of the Mackenzie Delta. Fronts were sometimes evident over the outer half of the shelf off the Delta. In 1986, bowheads were seen only in the northeast section of the Mackenzie shelf near the edge of the diffuse plume and outside the industrial area (Fig. 40c,d). They were absent over the rest of the shelf, within or closer to the industrial area, where diffuse plume water was found at the surface (Fig. 40c,d). Zooplankton biomass was higher off the eastern Tuktoyaktuk Peninsula where Mackenzie River influences were weak and where more bowheads were found than in the industrialized zone where Mackenzie River influences were strong and bowheads were scarce (Table 24).

On the Mackenzie Shelf, a change in the distribution of surface water properties occurred between 1 and 7 September 1986. There was a northeastward expansion of the Mackenzie river plume offshore from the Tuktoyaktuk Peninsula (Fig. 40c,d). There was also a northeastward shift in whale distributions off the Tuktoyaktuk Peninsula at about this time (Fig. 40c,d). The whale distributions may have changed in response to a change in the location of the Mackenzie River plume. Thomson et al. (1986) showed similar changes in whale distribution coinciding with changes in the position of the Mackenzie River plume during 1980 and 1981.

Important features of the distributions of physical oceanographic properties, zooplankton and bowheads in 1985-86 included the following: (1) zooplankton biomass was high in Arctic water and low in water influenced by the Mackenzie River; (2) in 1986, surface waters over most of the study area were under Mackenzie River influence; (3) upwelling occurred along the Yukon coast as a result of local southerly winds as well as east winds, and brought Arctic water to the surface; (4) zooplankton biomass along the Yukon coast was high and feeding bowheads were found in the area; and (5) over the Mackenzie shelf in 1986, bowheads were found where Mackenzie River influences were weakest and zooplankton biomass highest. Nevertheless, it seems likely that (6) the presence of the Mackenzie plume is an important and necessary component of the physical processes which lead to higher concentrations of zooplankton, such as coastal upwelling and the aggregation of zooplankton along fronts. These physical concentrating mechanisms, which are complex and difficult to study, represent important, albeit indirect influences of the Mackenzie River.

Annual Variability

In 1985, the diffuse plume extended to the northwest along the full length of the Yukon coast, and into the Alaskan Beaufort Sea (Bradstreet and Fissel 1986). The northwestern extent of the plume was unusually large, and was attributed to sustained easterly winds experienced in August 1985, and the unusually extensive ice cover present over the Mackenzie Shelf in July and August 1985 (Fissel et al. 1987). The large quantities of sea-ice to the east may have diverted more plume water than normal to the west. In both years, west of Kay Point, diffuse plume water appeared to track northwest along the continental shelf edge. This advection pattern also had been observed in satellite data from previous years (Borstad 1985; Thomson et al. 1986).

A common feature of the physical oceanographic regime of our study area in 1985 and 1986 was the occurrence of cold, saline Arctic water at the surface along the Yukon coast between Shingle and Kay Points. In 1985, a cold band of water was also present west of Herschel Island. In 1985, the presence of Arctic water at the surface close to shore was attributed to large scale coastal upwelling driven by the easterly winds (Bradstreet and Fissel 1986). The subsurface distribution of water properties suggested that upwelling was occurring from depths of 20 to 40 m (Bradstreet and Fissel 1986; Fissel et al. 1987). In 1986, the surface front at the offshore edge of the cold water mass in southern Mackenzie Bay had gradients comparable in intensity to those observed in 1985. However, in 1986 the area of Arctic water at the surface was apparently caused by strong but local southwesterly (offshore) winds, and was confined to the portion of the Yukon coast between Shingle and Stokes Point, and limited to depths of 20 m or less. Some combination of shallow water upwelling and advection was the apparent cause in 1986. The area of cold water at the surface was smaller in 1986 than in 1985. The results suggest that upwelling and strong fronts may occur along the Yukon coast in the Shingle Point to Kay Point area under differing wind conditions.

Whatever the driving mechanisms, conditions off the Yukon coast were similar in 1985 and 1986. In both years upwelling and other processes caused offshore displacement of the Mackenzie River plume. In both years the surface water consisted of cold saline Arctic water. This water apparently originated from deeper depths in 1985 than in 1986. Zooplankton biomass and bowhead utilization of the area were similar in 1985 and 1986 (Table 24, 27), although species composition of the zooplankton differed (Table 24). *Limnocalanus macrurus* was less abundant in 1986 than in 1985. It is not known whether the reduced upwelling in 1986 was the cause of the reduced abundance of *L. macrurus* in that year.

Comparisons of oceanographic conditions over the Mackenzie Shelf in 1985 and 1986 are more difficult to make because few oceanographic data were obtained there in 1985. Surface temperature data obtained from the satellite images of 20-21 August and 13 September 1985 (Borstad et al. 1986) suggest that the diffuse plume was confined to the inner half of the Mackenzie Shelf. However it is possible that the diffuse plume extended to the outer shelf as well. The remnants of open pack ice persisted over the outer shelf throughout the summer of 1985. This ice would have reduced surface temperatures considerably even if the plume extended into the area affected by ice. Hence, temperature data alone might be insufficient to define the outer boundary of the plume. Thomson et al. (1986) speculated that extensive ice cover, persisting throughout the summer, would reduce the rate of natural dispersion and partially contain the plume on the shelf. Based on this reasoning, diffuse plume water may have extended into the open pack ice and occupied a much greater proportion of the Mackenzie shelf surface layer than suggested by thermal satellite data.

Aerial survey data showed that bowhead use of waters off the Yukon and Mackenzie Delta was similar in 1985 and 1986. However, bowheads were apparently more abundant off the Tuktoyaktuk Peninsula in 1986 than in 1985 (Table 27). Uncorrected density estimates are not available for late August 1986; however, raw aerial survey data show similar numbers of bowheads in the area in late August and early September of 1986 (Fig. 40c,d). In 1985 few whales were found north of the Tuktoyaktuk Peninsula; many more were present in 1986. Containment of the Mackenzie plume by ice may have caused Mackenzie

River influences to be much stronger off the Tuktoyaktuk Peninsula in 1985 than in 1986. However, in the absence of ship-based oceanographic and zooplankton data from this area in 1985, we cannot make definite statements about the relationship between whale distributions and oceanographic conditions.

Table 27. Uncorrected estimates of numbers of bowhead whales in various regions of the southeastern Beaufort Sea in 1985 and 1986. These estimates are uncorrected for whales that were below the surface.

		Yukon Zone	Mackenzie Delta Zone	Tuktoyaktuk Peninsula Zone
1985[a]	Late August	190	94	11
	Early September	179	50	0
1986[b]	Late August	40	81	296
	Early September	100	71	250

[a] Norton and Harwood (1986).
[b] Ford et al. (in prep.).

In summary, the oceanographic conditions over the Mackenzie Shelf may have differed considerably between 1985 and 1986. In 1985, a layer of comparatively fresh water may have been found over most of the shelf. In 1986, a mixture of diffuse plume water and Arctic water was present at the surface over parts of the eastern half of the shelf and over the outer portion of the western shelf. Bowheads made extensive use of the eastern portion of the shelf in 1986 but were rare there in 1985. Conditions off the Yukon coast were similar in 1985 and 1986, and zooplankton biomass and use by bowheads were similar in both years.

Characteristics of Bowhead Feeding Areas

Zooplankton sampling among feeding bowheads has been conducted along the Mackenzie Bay portion of the Yukon coast in 1985 and 1986 (Bradstreet and Fissel 1986; this study), farther west along the Yukon coast near Komakuk in

1986 (Griffiths et al. 1987), along the coast off the Kongakut Delta in the eastern Alaskan Beaufort Sea in 1986 (Griffiths et al. 1987), farther offshore north of the Mackenzie Delta in 1980 and 1981 (Griffiths and Buchanan 1982), and off the eastern Tuktoyaktuk Peninsula in 1986 (this study). Aerial observations of feeding whales were made near Komakuk in 1985, but zooplankton sampling was not conducted there in 1985 (Richardson et al. 1987b).

Nearshore Feeding Areas

Most of the zooplankton sampling that has been conducted near feeding whales has been in nearshore waters along the Yukon coast and in the eastern Alaskan Beaufort Sea. In most of these areas and years there was a cold saline band of Arctic water close to the shore. Offshore of this band, water was fresher, warmer and more turbid than within this nearshore band. Off the Mackenzie Bay portion of the Yukon coast in 1985 and probably in 1986, this band of Arctic water was the result of nearshore upwelling. In 1985 cold saline water was brought to the surface both in Mackenzie Bay and near the Alaska border by classical wind-driven upwelling. In 1986 cold saline water from shallow depths ($\leq$20 m) was brought to the surface in Mackenzie Bay when local southwesterly winds pushed the surface layer away from the coast. At feeding locations off Komakuk and the Kongakut Delta in 1986, a nearshore band of cold saline water was overlain by warm turbid water. Strong horizontal gradients in temperature and salinity were found between the cold saline nearshore waters and the warm freshened offshore waters.

Zooplankton biomass associated with feeding whales in these nearshore areas was high (Table 28) compared to average values for the Beaufort Sea. Average biomass in the water column at stations where feeding whales were observed from the ship ranged from 455 to 1228 mg/m^3 (n = 6; excludes stations where whales were present but no evidence of feeding). Maximum biomass within layers of concentrated zooplankton that were evident on the echosounder was, at most stations with whales, over 1 g/m^3. At one station the maximum was close to 4 g/m^3 (Table 28). At all of these nearshore stations _Limnocalanus macrurus_ was the dominant zooplankter. At most of these stations _L. macrurus_ accounted for 80% or more of total zooplankton biomass (Table 28).

Table 28. Characteristics of bowhead feeding areas. Mean biomass is biomass in oblique tows. Maximum biomass is the biomass in the horizontal tow with the largest biomass at each station; these horizontal tows were guided to the depth of maximum biomass via echosounder. The depth at which the maximum biomass occurred is also shown. Other relevant biomass estimates in horizontal tows are also shown. Dominant taxa in oblique tows or, when unavailable in horizontal tows, are shown.

			Zooplankton					
			Biomass (mg/m^3)			Dominant Zooplankters in Horizontal Tow		
Location	Date	Water Depth (m)	Mean	Maximum	Depth of Max. Biomass (m)	Taxa (%)	Species (%)	Bowheads
This Study								
1. King Point, Yukon Coast 69°05'N 137°47'W	5 Sep 86	14	776	1543	3	Copepods (91%)	Limnocalanus macrurus (86%)	About 12 whales observed from ship; probably feeding
2. King Point, Yukon Coast 69°08'N 137°38'W	5 Sep 86	21	455	771	14	Copepods (61%)	Limnocalanus macrurus (26%)	3 whales observed from ship possibly feeding
3. North of Tuktoyaktuk 70°42'N 132°53'W	30 Aug 86	49	369	-[a]	-[a]	Copepods (85%)	Calanus hyperboreus (76%)	Whales observed within 50 m of ship
4. Off E. Tuk. Penin. 70°44'N 130°46'W	3 Sep 86	36	527	-[a]	-[a]	Copepods (87%)	Calanus hyperboreus (69%)	3 whales observed within 500 m of ship
5. North of Shingle Point 69°30'N 136°32'W	8 Sep 86	11	-[b]	281	10	Mysids (49%) Fish (23%)	Mysis litoralis (49%)	None seen from boat; six whales seen on seaward side of front on 7 September
Griffiths et al. 1987								
6. Off Kongakut Delta 69°50'N 141°52'W	5 Sep 86	14	1228	3023	10	Copepods (96%)	Limnocalanus macrurus (95%)	Feeding whales observed from boat and aircraft
7. 69°49'N 141°51'W	6 Sep 86	11	853, 318	2886	8	Copepods (91%)	Limnocalanus macrurus (88%)	Feeding whales observed from boat and aircraft
8. 69°50'N 141°36'W	7 Sep 86	22	912	2137	15	Copepods (95%)	Limnocalanus macrurus (94%)	Feeding whales observed from boat and aircraft
9. West of Herschel Is. 69°36'N 139°32'W	4 Sep 86	17	96	75	8	Hydrozoa + Ctenophores (38%)	Aglantha digitale (26%)	None seen from boat; feeding whales seen from aircraft previous day
10. Off Clarence Lagoon 69°38'N 140°49'W	7 Sep 86	12	105	3847	8	Hydrozoa + Ctenophores (42%)	Limnocalanus macrurus (32%)	1 whale near by; several feeding whales seen from aircraft previous day

Continued...

Table 28. Concluded.

Location	Date	Water Depth (m)	Zooplankton					Bowheads
			Biomass (mg/m^3)		Depth of Max. Biomass (m)	Dominant Zooplankters in Horizontal Tow		
			Mean	Maximum		Taxa (%)	Species (%)	
Bradstreet and Fissel (1986)								
11. Off Kay Pt., Yukon Coast. 69°27'N 138°04'W	27 Aug 85	64	288	1098	8	Copepods (92%)	*Limnocalanus macrurus* (77%)	Observed from boat
12. Off King Pt., Yukon Coast. 69°05'N 137°47'W	28 Aug 85	12	n/a	2142	1	Copepods (99%)	*Limnocalanus macrurus* (97%)	Observed from boat; 1 was surface feeding
13. Off King Pt., Yukon Coast. 69°08'N 138°00'W	29 Aug 85	21	836	1203	9	Copepods (94%)	*Limnocalanus macrurus* (88%)	Observed water-column feeding from boat
14. Off Kay Pt., Yukon Coast. 69°16'N 138°16'W	29 Aug 85	25	n/a	2294 693	8 1	Copepods (98%)	*Limnocalanus macrurus* (84%)	Observed some water-column feeding and some surface feeding from boat
Griffiths and Buchanan (1982)								
15. Off Richards Island, Mackenzie Delta 70°00'N 135°43'W	18-19 Aug 81	26	n/a	886 216	15 0	Copepods (79%) (70%)	*Calanus hyperboreus*	30 whales observed surface feeding (aircraft and boat observations)

[a] echosounder not functioning.

[b] No oblique tows taken.

Most of the whales that fed in nearshore areas in 1983-86 were subadults (Richardson et al. 1985a, 1987b; Davis et al. 1986a,b; Cubbage and Calambokidis 1987a,b). Use of nearshore areas by subadults was not consistent. Subadults did not feed along the shore in the eastern Alaskan Beaufort Sea in 1985 and they were present there for less than a week in 1986 (Richardson et al. 1987b). Farther east, off Komakuk, subadults were present for several weeks in 1984, 1985 and 1986 (Davis et al. 1986a,b; Richardson et al. 1987a,b). Subadults have been found along the Yukon coast in southern Mackenzie Bay each year since 1983. They have been present in this area for about three to six weeks.

Feeding on the Mackenzie Shelf

Feeding bowheads were common north of the Mackenzie Delta in 1980 and to a lesser extent 1981, but few have been observed in this area since 1981. Thomson et al. (1986) speculated that use of this area by feeding bowheads may be related to the distribution of the Mackenzie River plume: when the area is overlain by Mackenzie River water zooplankton biomass is low and whales avoid the area; when Arctic water is present zooplankton biomass is high and feeding whales are common.

Griffiths and Buchanan (1982) sampled near feeding bowheads north of the Delta in 1980 and 1981. They used vertical tows in 1980 and horizontal tows in 1981. During the first half of August 1981, the area was overlain with Mackenzie River water of low salinity. Bowheads were scarce and zooplankton biomass was 150 mg/m3 (mean integrated biomass from horizontal tows). During the latter half of August, a change in the wind reduced the influence of Mackenzie River water, salinity increased and zooplankton biomass increased to 340 mg/m3, and feeding bowheads were present. In 1980, Mackenzie River influences were not great in this area; salinity was similar to that of late August 1981 and many bowheads were present throughout August. *Calanus hyperboreus* and *Calanus glacialis* were the dominant copepods in this area in 1980 and 1981.

In late August and early September 1986, the diffuse plume was found over much of the area north of the Delta but not off the eastern Tuktoyaktuk Peninsula (Fig. 41). Whales were common only in the latter area. Average zooplankton biomass also was higher off the eastern Tuktoyaktuk Peninsula than off the Delta (Fig. 41). Thus the distribution of whales off the Delta and Tuktoyaktuk Peninsula appeared to be related to the distribution of average zooplankton biomass and the distribution of the plume (Fig. 41). *Calanus hyperboreus* and *Calanus glacialis* were the dominant zooplankters off the eastern Tuktoyaktuk Peninsula. *Calanus hyperboreus* accounted for most of the zooplankton biomass in tows taken at two stations that were sampled near whales (Table 28).

Whales feed in layers of concentrated zooplankton where the biomass is higher than the average biomass in the water column. Thus to compare food availability in various areas it would be most appropriate to compare the frequency of dense zooplankton patches in different areas, and the zooplankton biomasses within the dense patches present in various areas. Unfortunately, hydroacoustic sampling in 1986 was not very useful in defining zooplankton distribution, and we have few data on the occurrence of patches and the biomass of zooplankton within patches.

Within these limitations, the 1986 results are consistent with the hypothesis that use of the Mackenzie shelf area by bowheads is related to the presence of Mackenzie River water. When the influence of Mackenzie River water is strong, zooplankton biomass is low and whales are scarce. When Arctic water is found at the surface, zooplankton biomass tends to be high and whales are more commonly present.

Zooplankton Biomass Near Feeding Whales

The mean biomass found within layers of concentrated zooplankton that were evident on the echosounder near feeding whales was 1400 mg/m^3 in the Canadian Beaufort Sea and 1707 mg/m^3 in the eastern Alaskan Beaufort Sea (Table 29). For all areas the mean of the maximum biomasses found at each whale feeding station was 2041 mg/m^3 (Table 29). These values are much higher than the mean biomass of zooplankton taken within layers of concentrated

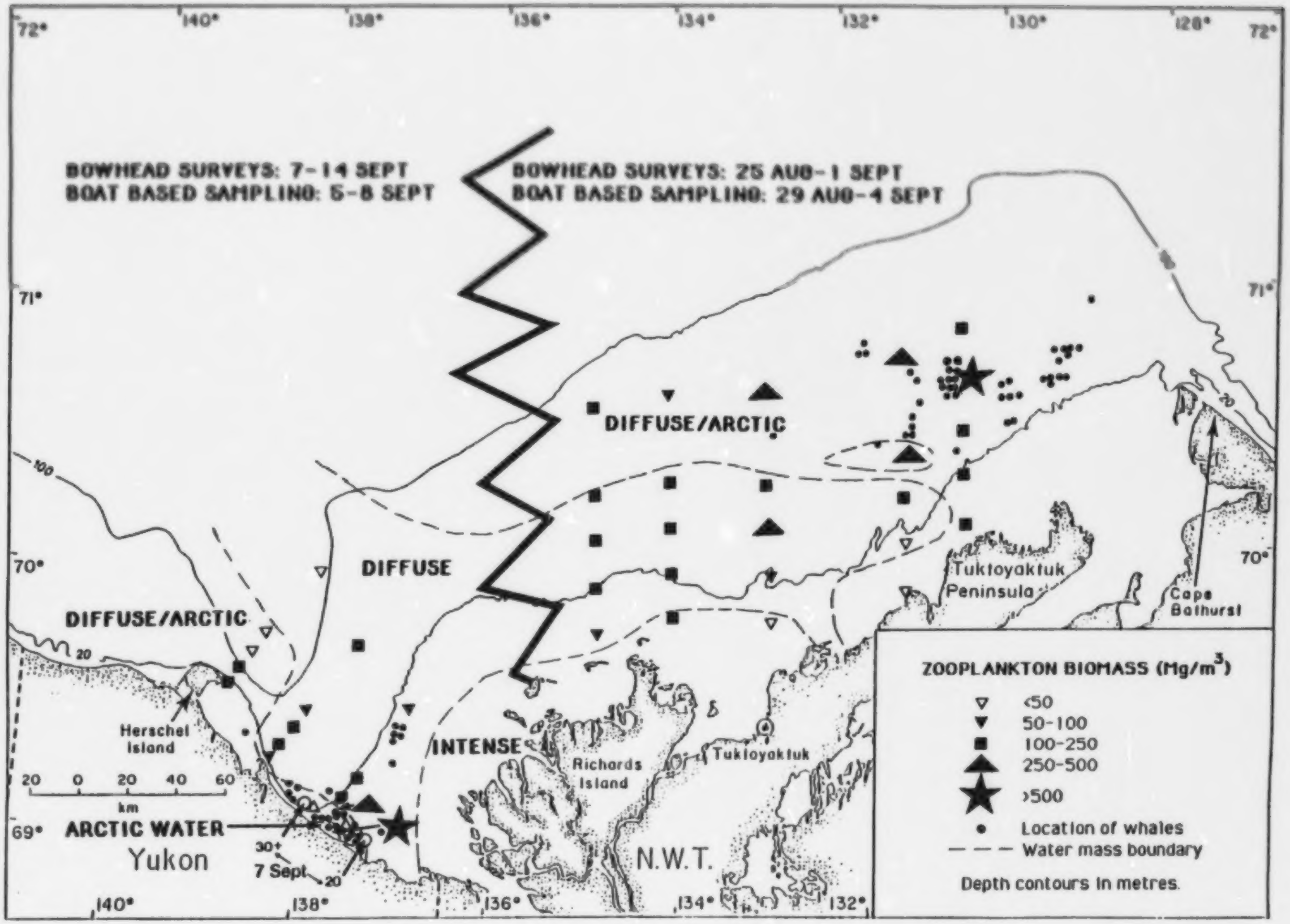
BOWHEAD SURVEYS: 7-14 SEPT
BOAT BASED SAMPLING: 5-8 SEPT
BOWHEAD SURVEYS: 25 AUG-1 SEPT
BOAT BASED SAMPLING: 29 AUG-4 SEPT
72°
140°
138°
136°
134°
132°
130°
128°
71°
70°
69°
DIFFUSE/ARCTIC
DIFFUSE
DIFFUSE/ARCTIC
INTENSE
ARCTIC WATER
Yukon
N.W.T.
Herschel Island
Richards Island
Tuktoyaktuk
Tuktoyaktuk Peninsula
Cape Bathurst
100
20
30
7 Sept
20 0 20 40 60
km
ZOOPLANKTON BIOMASS (Mg/m³)
▽ <50
▼ 50-100
■ 100-250
▲ 250-500
★ >500
● Location of whales
— — Water mass boundary
Depth contours in metres.

Figure 41. Zooplankton biomass in oblique tows and location of the Mackenzie River plume defined by oceanographic sampling from 25 August to 4 September 1986 off the Delta and Tuk. Pen. and from 5 to 8 September 1986 off the Yukon coast. Locations of whales seen during aerial surveys that corresponded in time to ship-based sampling in each of the two areas are also shown. Whale positions from Harwood and Norton (1986, in prep.).

Table 29. Biomass of zooplankton in horizontal tows taken near feeding bowhead whales in the Alaskan and Canadian Beaufort Sea in 1985 and 1986. Only horizontal tows taken within zooplankton layers evident on the echosounders are considered. Data are from this study, Bradstreet and Fissel (1986) and Griffiths et al. (1987). Numbers in parentheses refer to sampling locations listed in Table 28.

	Zooplankton Biomass (mg/m^3)			
Area	Mean	± s.d.	(n)	
All Horizontal Samples				
Canadian Beaufort Sea	1400	524	10	Definite feeding stations only (1, 10-13)
	1142	619	14	Includes definite and probable feeding stations (1, 2, 10-13)
Alaskan Beaufort Sea	1707	982	7	Definite feeding stations only (5-7)
	1899	1276	10	Includes stations where feeding whales present the previous day (5-9)
All Areas	1526	735	17	Definite feeding stations only
	1457	999	24	Includes definite and probable whale feeding stations and stations where whales were observed the previous day.
Maximum Biomass at each Station				
All Areas	2041	717	8	Definite feeding stations only
	1911	1103	11	Includes definite and probable whale feeding stations and stations where whales were observed the previous day.

zooplankton that were evident on the echosounder at stations where no bowheads were seen:

Southeastern Beaufort Sea 1986	107 mg/m^3	n = 40
Yukon Coast 1985	216 mg/m^3	n = 16
Eastern Alaskan Beaufort Sea 1986	283 mg/m^3	n = 24

Mean biomasses in the water column as a whole were, of course, lower than those in the layer of maximum zooplankton biomass, but the same contrast was evident between stations with bowheads vs. without bowheads: 745 mg/m^3 (n = 7) vs. 147 mg/m^3 (n = 72). These averages consider the 1985 and 1986 data from the Canadian Beaufort and the 1986 data from the Eastern Alaskan Beaufort.

Feeding in Other Areas

Bowheads arrive in Amundsen Gulf and the eastern part of the Beaufort Sea in May and June. We have no information on their feeding behaviour nor on the availability of potential prey while they are in these areas. Their length of stay in Amundsen Gulf and areas to the north and east of Cape Dalhousie is at least as long as their stay in the southeastern Beaufort Sea later in summer. These areas may also be important feeding grounds for bowheads.

In late July or early August, bowheads begin to appear in substantial numbers over the continental shelf of the southern Beaufort Sea (Richardson et al. 1985a, 1987a). Most of the animals that enter nearshore waters are subadults, and most of the sampling conducted near feeding whales has been conducted near these subadults (Table 28). Adults are proportionately more common farther offshore and in Amundsen Gulf. However it has not yet been possible to account for the whereabouts of all adult bowheads during summer (Davis et al. 1986a,b; Cubbage and Calambokidis 1987a). We have little direct information on the biomass or species composition of zooplankton associated with feeding adults, but the results from mid-shelf feeding locations 3, 4 and 14 (Table 28) may be representative.

There is no direct evidence of winter feeding in bowheads (see Thomson and Richardson 1987). However, recent isotopic analysis of bowhead tissues suggests that small bowheads feed to a considerable extent outside the eastern Beaufort Sea (Schell et al. 1987). Some of this feeding presumably occurs during the spring and fall migrations, but some may also occur in winter. The isotopic evidence suggests that adults feed in different areas than subadults. There are few data on the species composition, biomass or isotopic content of zooplankton near feeding adults.

Some bowheads feed during the fall migration through the Alaskan Beaufort Sea. Almost all bowheads harvested at Kaktovik and Barrow in fall contain prey in their stomachs (Lowry and Frost 1984; Lowry et al. 1987). Bowheads that appeared to be feeding have been seen at many locations all across the Alaskan Beaufort Sea in autumn, although the consistency of feeding in autumn seems to decrease from east to west (Ljungblad et al. 1986).

Some bowheads feed off Barrow during spring migration, although this apparently occurs during only a minority of years (Carroll et al. 1987; Lowry et al. 1987). Nonetheless, some bowheads do interrupt spring migration to feed near the bottom or under the ice. There is no information on the extent of feeding during spring migration in areas other than Barrow.

In summary, most of the information on the species composition and biomass of zooplankton near feeding bowheads pertains to whales (mainly subadults) feeding close to shore during the latter part of the summer (Griffiths and Buchanan 1982; Bradstreet and Fissel 1986; Griffiths et all. 1987; this study). Subadults feed in the areas sampled by these workers for a maximum of about 6 weeks during late summer. Apart from a few stomach samples there is no information on feeding habits or feeding locations of subadults in other areas at other times. We do not know the location or characteristics of the main adult feeding grounds, nor do we know anything about the activities of bowheads during the first half of the summer.

Energetic Importance of the Southeastern Beaufort Sea to Bowheads

Bowheads migrate a long distance from the Bering Sea to the southeastern Beaufort Sea to feed. There is increasing evidence about the frequency of feeding during migration and perhaps while on the winter grounds (Lowry and Frost 1984; Ljungblad et al. 1986; Lowry et al. 1987; Schell et al. 1987). However, it is unlikely that bowheads meet all of their daily energetic requirements through feeding while migrating and while on the winter grounds (Thomson 1987b). While in the southeastern Beaufort Sea, bowheads must consume enough food to meet daily energetic requirements and to build up energy reserves for winter and the migration. In the following section we evaluate the importance of the study area to the population of bowhead whales and to individual bowheads. In order to do this we must estimate the total amount of zooplankton in the study area and the energetic requirements of bowhead whales.

Total Amount of Zooplankton in the Study Area

For the purposes of this discussion, the study area extends from Herschel Island in the west to Cape Dalhousie in the east and offshore to 72°N. Zooplankton sampling in this area in 1986 was confined to the continental shelf. For depths of 200 to 2000 m we have used the estimate of 100 mg/m3 used for the same depth range in the Alaskan Beaufort Sea by Thomson and Richardson (1987).

Total zooplankton biomass in the upper 50 m over the continental shelf was estimated to be about 350,000 MT (Table 30). About 320,000 MT would be present in the top 50 m of the water off the shelf in the northern part of the study area. Thus, in early September 1986 about 670,000 MT of zooplankton was present in the upper 50 m of the water column within the study area. Some additional zooplankton would be present below 50 m depth in offshore waters, but zooplankton biomass tends to decline below 50 m depth (Griffiths et al. 1987).

Zooplankton Available to Bowheads

Bowhead whales feed preferentially in areas with a higher than average biomass of zooplankton (Griffiths and Buchanan 1982; Bradstreet and Fissel 1986; Griffiths et al. 1987; this study). Other species of baleen whales also feed preferentially in areas with a higher than average biomass of potential prey. Baleen whales apparently cannot obtain enough food by feeding in areas of average prey abundance; they must feed selectively in areas of concentrated prey (Nemoto 1970; Brodie et al. 1978). Thus, not all of the zooplankton in the study area would be useful to feeding bowhead whales. Some of this zooplankton would occur in concentrations that are too low to permit economical feeding. We would expect that most feeding would be in areas where the zooplankton density is greater than a threshold biomass representing the minimum concentration for economical feeding.

Table 30. Estimated total wet weight of zooplankton in the upper 50 m of the study area in 1986.

Region	km^2	mg/m^{3a}	Biomass (MT)^b
Shelf <200 m Deep			
Yukon Coast	19317	173	115294
Industrialized Zone	17327	153	93457
E. Tuk Pen	19902	210	141181
Subtotal	56546		349932
200 m Isobath to 72°N	63688	100^c	318439
Total	120234	636	668371

[a] From Table 5.
[b] Adjusted for areas with depth <50 m.
[c] From Thomson and Richardson (1987).

Prolonged feeding in concentrations of food that are below the feeding threshold will not allow a whale to meet its daily food requirements and would necessitate feeding in higher concentrations at some other time. Most of our data on concentrations of food associated with feeding whales concern subadult animals, and the following discussion will deal mainly with subadults.

Thomson (1987b) has computed the theoretical energetic requirements of bowheads whales (Table 31). Subadult bowheads require about 444 kg/d for the 130 d spent on the summer feeding grounds. This estimate assumes that during migration and over winter bowheads consume enough food to meet 30% of daily maintenance requirements, and that the balance of daily requirements during migration and winter is met through fat reserves accumulated in summer. Given the mouth area calculated by Thomson (1987b) and assuming that feeding occurs for 16 h/d at a speed of 5 km/h, then a subadult would have to feed in zooplankton concentrations averaging 2.1 g/m^3 to meet its daily energetic requirements. This figure is higher than the mean of 1.5 g/m^3 for all tows taken within layers of concentrated zooplankton at sampling stations near feeding subadults and about the same as the mean of the maximum biomasses at each of these stations (2 g/m^3; Table 29).

Quantitative echosounder data can provide information about the proportion of the water that contains various biomasses of zooplankton (Griffiths et al. 1987). In order to consume a mean of 2.1 g/m^3, a bowhead in the eastern Alaskan Beaufort Sea would have had to feed in concentrations of at least 1.3 g/m^3 in 1985 and 1.75 g/m^3 in 1986 (Thomson and Richardson 1987). (The mean biomass in all locations with a biomass equal to or greater than these values was about 2.0 g/m^3.) About 12% of the zooplankton biomass over the eastern Alaskan Beaufort Sea shelf occurred in concentrations greater than 1.25 g/m^3 in 1985. In 1986 about 1.3% of biomass occurred in concentrations greater than the threshold of 1.75 g/m^3. Quantitative hydroacoustic data are not available from the Canadian Beaufort Sea, but the qualitative data presented by Bradstreet and Fissel (1986) imply that, in 1985, about 8% of the zooplankton biomass over the Yukon shelf occurred in concentrations greater than the feeding threshold. In the following discussion we assume that about 10% of total zooplankton biomass over the southeastern Beaufort Sea shelf occurred in concentrations that permitted economical feeding by subadult bowhead whales.

Table 31. Energetic requirements of bowhead whales (from Thomson 1987).

	Subadults	Adult Male	Adult Female[a]	Average Non-Calf
Mean Length (m)	10.8	14.5	14.5	12.4
Weight (MT)	24.9	53.7	53.7	37.7
Mouth Opening (m^2)	2.7	5.3	5.3	3.9
Individual Requirements				
Total annual (Kcal/yr x 10^5)	732	1455	1735	1091
food requirements (MT/yr)	71.5	142.0	169.2	106
Rate of food intake[b]				
No Winter Feeding (Kg/d)	550	1092	1302	815
Zooplankton Biomass Required (g/m^3)[c]	2.5	2.6	3.1	2.5
With Winter Feeding (Kg/d)[d]	444	881	1053	653
Zooplankton Biomass Required (g/m^3)	2.1	2.1	2.5	2.0
Population Requirements				
Number of Animals	2310	822	822	3954
Kcal x 10^8 /yr	1692	1196	1428	4316
Kg x 10^5 /yr	1651	1166	1393	4210
Kg x 10^5/d	12.7	9.0	10.7	32.4

[a] Cost of reproduction averaged over 3 years.
[b] Assuming 130 days of feeding during summer.
[c] Assumes feeding 16 h/d at 5 km/h.
[d] Assumes feeding in winter and during migration = 30% of daily maintenance requirements.

The most recent published estimate of the number of bowheads in the western Arctic population is 4417 (IWC 1986). For the purposes of energetic computations, Thomson (1987b) used Davis et al.'s (1983) estimates of the size structure of the population: 52.3% subadult, 37.2% adults and 10.5% calves. Thus there would be about 2310 subadult bowheads. An estimated 800 to 3900 bowheads (mean of 2400 in late August and 2000 in early September) were in the ESRF/BEMP aerial survey study area in 1985 (Norton and Harwood 1986) and about 2600 were present in early September of 1986 (Harwood and Norton 1986). Many of the bowheads in this area in 1985 and 1986 were subadults (Davis et al. 1986b; Cubbage and Calambokidis 1987a). If there are about 2300 subadults in the population, most of them would have been present in the ESRF/BEMP aerial survey study area.

A subadult weighs about 25 MT and has a mouth area of 2.7 m^3 (Table 31). If it feeds for 16 h/d at a speed of 5 km/h in zooplankton concentrations averaging 2 g/m^3, it will consume 432 kg/d. If all subadults are in the study area for a maximum of six weeks during summer, then they could consume about 42,000 MT. This represents about 10% of the estimated annual food requirements of the population and about 25% of the requirements of all subadults. (A subadult bowhead consumes about 71.5 MT/yr. If it spends six weeks in the study area, then about 18.5 MT or about 25% of its annual requirements would be consumed there.) If about 10% of the zooplankton biomass that occurs over the shelf is in concentrations that permit economical feeding, then about 35,000 MT are available. This availability figure is about the same as the estimated consumption by subadults in a 6-wk period (35,000 vs. 42,000 MT).

The official population estimate for bowhead whales is under revision (IWC, in prep.). It is now believed that the population of bowheads may be as high as 7200 animals. If so, there may be about 3765 subadults and they would consume about 68,300 MT if all of them were in the study area for six weeks. Our estimates of zooplankton availability are too imprecise to determine if this level of utilization would be beyond the carrying capacity of the environment. However, given our estimates of zooplankton standing crop, this figure may be near the upper limit of zooplankton availability.

Bowheads are not the only consumers of zooplankton in the Beaufort Sea. Hydrozoans, chaetognaths, hyperiid amphipods and ctenophores eat herbivorous zooplankton. Arctic cod are the major vertebrate consumers of zooplankton in the Beaufort Sea. Competition for food between bowheads and Arctic cod is a possibility (Frost and Lowry 1984). Thus, it cannot be assumed that the entire standing stock of zooplankton is available to bowheads.

The southeastern Beaufort Sea is an important feeding ground for subadult bowheads but seems to be less important for adults. Zooplankton standing crop in that area may be insufficient to support the entire population of bowheads.

Thomson and Richardson (1987) concluded that in 1985 and 1986, the eastern Alaskan Beaufort Sea was relatively unimportant to the energetic requirements of the bowhead population as a whole. Other parts of their range have not been examined in this way. Because of the large food requirements of the bowhead population and the relatively low biomass of zooplankton found in the Beaufort Sea, no one area can meet the nutritional requirements of the entire population. Rather, it appears that various segments of the population feed in different areas at different times. All of these areas may be important to the feeding ecology of the species.

Summary and Implications

In 1985 and 1986, the distribution of zooplankton biomass in the southeastern Beaufort Sea was related to the distribution of the Mackenzie River plume. Biomass was highest in water that was unaffected by the plume and lowest where Mackenzie River influences were greatest. In both years, bowheads fed at locations where zooplankton biomass was high. The distribution of bowheads in 1986 was consistent with the hypothesis that bowheads tend to avoid areas strongly influenced by the Mackenzie Plume.

Limnocalanus macrurus was the dominant copepod in nearshore waters off the Yukon coast in both 1985 and 1986 and is very important to the feeding ecology of the bowheads that feed there in some years. Little is known about the ecology and life history of *Limnocalanus* in Arctic marine waters. Along the Yukon coast, upwelling, the abundance of *L. macrurus* and the abundance of bowheads are all variable. The relationships among these three variables are not well known. However, the abundance of *Limnocalanus macrurus* is related to water mass characteristics, which are affected by the amount of upwelling, and bowheads tend to feed at nearshore locations where *L. macrurus* is concentrated. Many bowheads were present along the Yukon coast each year since 1983, but not in 1980-82. A hypothesis that bowheads are common along the Yukon coast in years when there is upwelling and when the biomass of *L. macrurus* is high warrants further investigation by retrospective analysis of existing data as well as further fieldwork.

Most bowheads that feed in nearshore portions of the study area are subadults, and most of the subadults in the population may use the study area for a few weeks in the summer. Over a 6-wk period, they may consume about 26% of their annual energetic requirements. This quantity of zooplankton may be a substantial fraction of the amount of zooplankton that is present over the shelf in exploitable concentrations. Most of the information about feeding behaviour and food availability to bowheads has been collected during these six weeks in late summer when bowheads are on the southeastern Beaufort Sea shelf. We have no information on the feeding activities of subadults before they arrive on the shelf, and few data on feeding by adults at any time.

It has been hypothesized that bowheads may now be avoiding the zone of industrial activity in the Beaufort Sea as a long term response to noise and disturbance (ESL et al. 1986). This study did not directly address that hypothesis; rather, it has been undertaken to advance our knowledge of the role of natural processes in determining the distribution of bowhead whales. Such knowledge is required in order to address the disturbance hypothesis.

Thomson et al. (1986) speculated that bowhead whales avoided the Mackenzie River plume because zooplankton biomass was lower in water that was under the influence of the plume than in water that was away from the plume. They presented some evidence that zooplankton biomass at depth was lower where surface waters were of Mackenzie plume origin than where cold saline water was found at the surface. They compiled evidence showing that, in August 1980 and the latter half of August 1981, zooplankton biomass was high in the industrialized zone, Mackenzie River influences were minimal, and bowheads were present. In 1983 the industrialized zone was more strongly under the influence of the Mackenzie River plume and bowheads were scarce (Thomson et al. 1986). However, in 1982 Mackenzie River influences were minimal and bowheads were absent from the industrial zone.

In 1985 and 1986, bowheads were again scarce in the industrialized zone, the area was under the influence of the Mackenzie River plume, and (at least in 1986) zooplankton biomass was low. All comparisons of zooplankton were made using the average biomass as determined with oblique or vertical tows. Bowheads feed in concentrations of zooplankton that contain a greater-than-average biomass, and it is the availability of concentrations of zooplankton that matters to bowheads. As a result of the technical problems encountered during the 1986 hydroacoustic program, we have little information on the relative occurrence of concentrated zooplankton patches in plume vs. non plume areas.

The distribution of bowhead whales is variable and not all of the factors that determine the movements and distribution patterns of these whales are known. It is clear that whale presence implies not only high mean zooplankton biomass, but also sufficiently high local biomass concentrations to make feeding economical for such a large cetacean. But does the absence of whales, especially in the industrial zone, imply low zooplankton biomass, too few patches of high zooplankton concentration, avoidance behaviour due to industry-related disturbances (past or present), or all three of these? Since industrial activity was very low in 1986, any avoidance through disturbance, should it have occurred at all, would most likely have been a long-term response to the higher levels of industrial activity of previous years. Regarding food availability, the data have shown that in waters <40 m deep the mean biomass did not differ significantly between those areas where bowheads were feeding (east of the industrial zone and off the Yukon coast) and where they were not (the industrial zone). Mackenzie River influence appears to be associated with whale absence (e.g., the industrial zone) unless there also prevail upwelling conditions and/or strong frontal dynamics which serve to increase biomass concentrations (e.g., off Yukon coast).

It is not known whether exploitable prey patches occurred in the industrial zone in 1986, since the hydroacoustic data were not correlated with zooplankton biomass and few, if any, whales occurred there. To assess whether prey concentrations occur in the industrialized area and if so whether they are less heavily used than those elsewhere, we need quantitative data on the relative frequencies of exploited versus unexploited concentrations of zooplankton in the industrialized area and other areas. This would require aerial observations of whale distribution and activities, closely coordinated with quantitative hydroacoustic sampling. Before such a program will be practical, it will be necessary to develop hydroacoustic techniques that provide reliable data on zooplankton in the complex water masses within the study area.

ACKNOWLEDGEMENTS

This study was undertaken for the Department of Indian and Northern Affairs, Canada, with the support of the Department of Supply and Services. We thank D. Stone, J. Moen, R. Hurst and F. McLennan for their help and advice.

Fieldwork for this project was carried out by the senior author and by R. Buchanan, M. Fabijan and N. Stallard of LGL Ltd.; G. Pierlot of Arctic Sciences Ltd. (ASL); P. Vonk of Environmental Sciences Ltd. (ESL); and R. Hurst and J. Moen of the Department of Indian and Northern Affairs, Canada. We were ably assisted in the field by Captain B. Moulton and the crew of the M.V. Arctic Ivik; W. Calvert of the Canadian Wildlife Service; Henry and Florence Nasogaluak, Tuktoyaktuk; and by H. Scott, Polar Continental Shelf Project, Tuk base. Field sampling benefitted from real-time information on the locations of bowhead whales provided by L. Harwood, University of Alberta; J.K.B. Ford, ESL; J.C. Cubbage, Cascadia Research Collective; and P. Norton, PN Research Projects.

J.R. Marko (ASL) carried out the processing and preliminary analysis of the satellite data. M. Fabijan, L. Graff and N. Stallard (LGL) undertook the laborious laboratory analyses of zooplankton; and P. Niewiarowski and A. Place, University of Pennsylvania, undertook caloric and lipid analyses of selected zooplankton samples. R. Birch (ASL) and C. Holdsworth (LGL) assisted with data processing. W. Griffiths (LGL) provided comparative zooplankton information from the Alaskan Beaufort Sea. F. Welsman, R. Stover, K. Bishop, B. Griffen, R. Evans and C. Holdsworth assisted with report preparation. The report benefitted from the reviews of W.J. Richardson, R.A. Davis, L. Lowry, J. Moen, J. Montague, D.L. Mackas and L. Harwood. Drs. R.A. Davis and W.J. Richardson (LGL) provided overall direction and we are especially grateful to them for their assistance.

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APPENDIX 1. Positions and times of CTD-transmissometer sampling locations, in chronological order.

	Station	Date	Time (GMT)	Latitude	Longitude	Depth (m)		
						Water (Chart)	Secchi	Data
Transect 6	51	28 Aug.	1423	69 59.0	131 26.6	10	0.5	9
	51A	29 Aug.	1429	70 02.0	131 26.6			13
	51B	29 Aug.	1513	70 05.0	131 26.6			15
	52	29 Aug.	1602	70 09.0	131 26.6			19
	52A	29 Aug.	1821	70 12.0	131 26.6			22
	52B	29 Aug.	1859	70 15.0	131 26.6			26
	53	29 Aug.	2334	70 19.0	131 26.6		1.5	28
	53A	29 Aug.	2257	70 22.0	131 26.6			37
	53B	29 Aug.	2327	70 25.0	131 26.6			37
	54	29 Aug.	2359	70 29.0	131 26.6		2.5	34
	54A	30 Aug.	0148	70 32.0	131 26.6			35
	54B	30 Aug.	0217	70 35.0	131 26.6			38
	54C	30 Aug.	0301	70 38.0	131 26.6			42
	54D	30 Aug.	0324	70 41.0	131 26.6			42
	54E	30 Aug.	0356	70 44.0	131 26.6			43
	55	30 Aug.	0419	70 49.0	131 26.6	49	10.0	49
Transect 7	60	30 Aug.	1211	70 42.3	132 52.5	43?	7.0	49
	59E	30 Aug.	1419	70 37.0	132 52.5			39
	59D	30 Aug.	1439	70 34.0	132 52.5			36
	59C	30 Aug.	1538	70 31.0	132 52.5			36
	59B	30 Aug.	1707	70 28.0	132 52.5			39
	59A	30 Aug.	1752	70 25.0	132 52.5			37
	59	30 Aug.	1828	70 22.3	132 52.5		2.5	30
	58B	30 Aug.	1850	70 19.0	132 52.5			36
	58A	30 Aug.	2108	70 15.6	132 52.5			33
	58	30 Aug.	2151	70 12.3	132 52.5		1.5	28
	57B	30 Aug.	2224	70 08.3	132 52.5			25
	57A	31 Aug.	0044	70 05.3	132 52.5			27
	57	31 Aug.	0108	70 02.3	132 52.5		4.5	23
	56B	31 Aug.	0132	69 58.3	132 52.5			16
	56A	31 Aug.	0312	69 55.3	132 52.5			10
	56	31 Aug.	0326	69 52.3	132 52.5	10	2.0	11
Transect 8	61	31 Aug.	1848	69 53.4	133 58.0	10	0.8	9
	61A	31 Aug.	1915	69 56.4	133 58.0			15
	61B	31 Aug.	2039	69 59.4	133 58.0			19
	62	31 Aug.	2039	70 03.4	133 58.0		2.5	23
	62A	31 Aug.	2229	70 06.4	133 58.0			23
	62B	31 Aug.	2259	70 09.4	133 58.0			28
	63	31 Aug.	2320	70 13.4	133 58.0		2.5	35
	63A	1 Sep.	0008	70 16.4	133 58.0			38
	63B	1 Sep.	0119	70 19.4	133 58.0			43
	64	1 Sep.	0145	70 23.4	133 58.0		2.2	51
	64A	1 Sep.	0259	70 26.4	133 58.0			55
	*64B	1 Sep.	0414	70 29.4	133 58.0			58
	*64C	1 Sep.	0449	70 32.4	133 58.0			52
	*64D	1 Sep.	0520	70 35.4	133 58.0			61
	64E	1 Sep.	0558	70 38.4	133 58.0			64

APPENDIX 1. Continued.

	65	1 Sep.	0658	70 43.4	133 58.0	62		55
Transect 9	70	1 Sep.	1509	70 40.3	134 50.0	58	15.0	55
	69E	1 Sep.	1544	70 35.3	134 50.0			58
	69D	1 Sep.	1708	70 32.3	134 50.0			58
	69C	1 Sep.	1839	70 29.3	134 50.0			52
	69B	1 Sep.	1918	70 26.3	134 50.0			54
	69A	1 Sep.	2011	70 23.3	134 50.0			50
	69	1 Sep.	2039	70 20.3	134 50.0		5.0	41
	68B	1 Sep.	2107	70 16.3	134 50.0			39
	68A	1 Sep.	2246	70 13.3	134 50.0			38
	68	1 Sep.	2315	70 10.3	134 50.0		1.5	36
	67B	1 Sep.	2341	70 06.3	134 50.0			30
	67A	2 Sep.	0143	70 03.3	134 50.0			28
	67	2 Sep.	0204	70 00.3	134 50.0		1.8	21
	66B	2 Sep.	0303	69 56.3	134 50.0			14
	66A	2 Sep.	0355	69 53.3	134 50.0			5
	66	2 Sep.	0412	69 50.3	134 50.0	10	1.3	7
Transect 11	76	3 Sep.	0105	70 13.7	130 46.1	10	0.8	11
	76A	3 Sep.	0116	70 16.7	130 46.1			12
	76B	3 Sep.	0521	70 19.7	130 46.1			13
	77	3 Sep.	0553	70 23.7	130 46.1		2.5	19
	77(2)	3 Sep.	1241	70 23.7	130 46.1			19
	77A1	3 Sep.	1321	70 26.7	130 46.1			22
	77B	3 Sep.	1422	70 29.7	130 46.1			22
	78	3 Sep.	1449	70 33.7	130 46.1		5.0	25
	78A	3 Sep.	1510	70 36.7	130 46.1			30
	78B	3 Sep.	1750	70 39.7	130 46.1			33
	79	3 Sep.	1808	70 43.7	130 46.1		9.0	34
	79A	3 Sep.	1834	70 47.0	130 46.1			37
	79B	3 Sep.	2140	70 50.5	130 46.1			37
Tow Stn 80	79C	3 Sep.	2210	70 53.8	130 46.1		9.0	44
	79D	3 Sep.	2244	70 57.3	130 46.1	46		41
E-W Trans.	81	4 Sep.	0248	70 53.3	130 56.0	44		41
	82	4 Sep.	0309	70 52.8	131 06.5			49
	83	4 Sep.	0401	70 52.0	131 18.5			49
	84	4 Sep.	0441	70 51.3	131 30.0			51
	85	4 Sep.	0530	70 50.6	131 43.0			51
	86	4 Sep.	0623	70 50.0	131 54.5			54
	87	4 Sep.	0659	70 49.5	132 06.2			54
	88	4 Sep.	0737	70 49.4	132 16.2			57
	89	4 Sep.	0835	70 48.9	132 31.0			57
	90	4 Sep.	0910	70 48.3	132 42.5			57
	91	4 Sep.	0954	70 47.4	132 54.3			54
	92	4 Sep.	1051	70 47.1	133 04.0			54
	93	4 Sep.	1134	70 46.1	133 16.3			59
	94	4 Sep.	1224	70 45.5	133 28.1			67
	95	4 Sep.	1319	70 44.3	133 46.1			69
	96	4 Sep.	1404	70 43.7	133 53.0	65		67
Transect 8	65-2	4 Sep.	1459	70 43.4	133 58.0	62	7.0	67
	64e-2	4 Sep.	1836	70 38.4	133 58.0			61
	64d-2	4 Sep.	1905	70 35.4	133 58.0			60
	64c-2	4 Sep.	1929	70 32.4	133 58.0			55

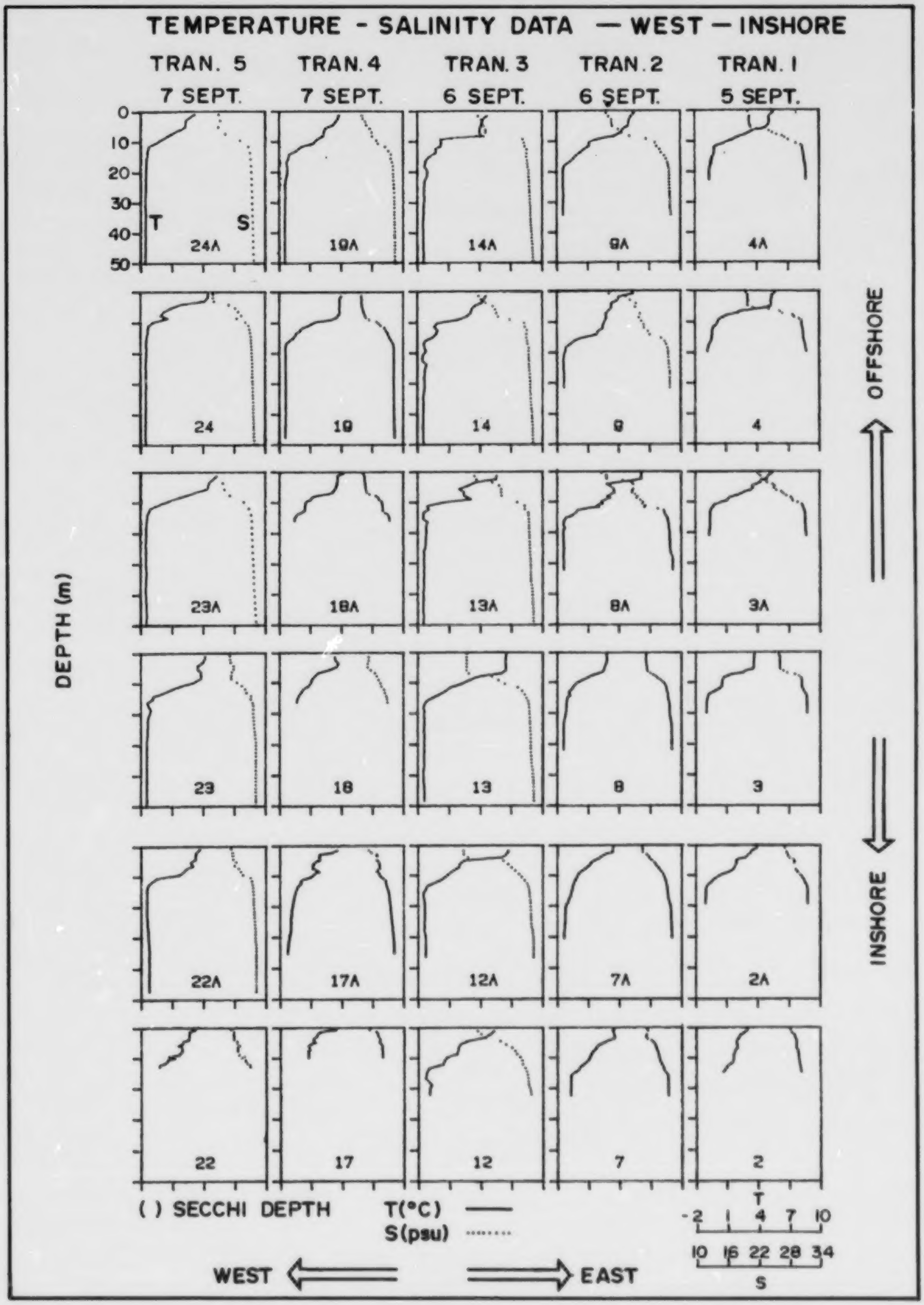
APPENDIX 1. Continued.

	64b-2	4 Sep.	1956	70 29.4	133 58.0			54
	64a-2	4 Sep.	2030	70 26.4	133 58.0			52
	64-2	4 Sep.	2054	70 23.4	133 58.0		4.0	50
	63b-2	4 Sep.	2125	70 19.4	133 58.0			31
	63a-2	5 Sep.	0033	70 16.4	133 58.0			43
	63-2	5 Sep.	0057	70 13.4	133 58.0		4.0	40
	62b-2	5 Sep.	0128	70 09.4	133 58.0			32
	62a-2	5 Sep.	0314	70 06.4	133 58.0			27
	62-2	5 Sep.	0330	70 03.4	133 58.0		3.0	23
	61b-2	5 Sep.	0434	69 59.4	133 58.0			18
	61a-2	5 Sep.	0623	69 56.4	133 58.0			12
	61-2	5 Sep.	0649	69 53.4	133 58.0	10		11
E->W Trans	97	5 Sep.	0749	69 51.4	134 25.9			11
	97A	5 Sep.	0958	?	?			11
Transect 1	30	5 Sep.	1527	69 31.8	136 46.1	13	2.8	13
	5C	5 Sep.	1800	69 27.9	136 54.6			13
	5B	5 Sep.	1817	69 24.0	137 03.2			16
	5A	5 Sep.	1923	69 20.1	137 11.8			17
	5	5 Sep.	1933	69 16.1	137 20.4		3.8	22
	4A	5 Sep.	2013	69 14.2	137 24.6			22
	4	5 Sep.	2158	69 12.3	137 28.7		2.5	19
	3A	5 Sep.	2234	69 10.1	137 33.1			21
	3	6 Sep.	0022	69 08.0	137 37.5			20
	2A	6 Sep.	0049	69 06.3	137 42.2			19
	2	6 Sep.	0236	69 04.5	137 46.9	11	2.3	14
Transect 2	7	6 Sep.	0640	69 07.9	137 58.3	20		22
	7A	6 Sep.	0711	69 09.1	137 55.2			30
	8	6 Sep.	0728	69 10.8	137 49.5			31
	8A	6 Sep.	0752	69 13.2	137 46.0			32
	9	6 Sep.	0820	69 15.7	137 42.5			31
	9A	6 Sep.	0835	69 17.2	137 37.4			34
	10	6 Sep.	0904	69 18.8	137 32.4			34
	10A	6 Sep.	0926	69 22.6	137 24.6			39
	10B	6 Sep.	1016	69 26.5	137 16.9			33
	10C	6 Sep.	1053	69 30.4	137 09.1			26
	31	6 Sep.	1131	69 34.3	136 58.6	22		22
E->W Trans	103	6 Sep.	1210	69 37.2	137 04.2			29
	104	6 Sep.	1244	69 40.1	137 09.8			41
	105	6 Sep.	1317	69 43.0	137 15.4			47
Transect 3	32	6 Sep.	1348	69 46.0	137 21.0	70	3.5	51
	15C	6 Sep.	1649	69 47.1	137 29.6			56
	15B	6 Sep.	1745	69 34.3	137 47.0			58
	15	6 Sep.	1839	69 30.5	137 55.7		3.5	51
	14A	6 Sep.	1918	69 28.5	137 59.9			63
	14	6 Sep.	2153	69 26.5	138 04.1		4.5	63
	13A	7 Sep.	0009	69 24.5	138 08.2			58
	13	7 Sep.	0030	69 22.5	138 12.4		3.5	48
	12A	7 Sep.	0054	69 20.3	138 17.0			36
	12	7 Sep.	0314	69 19.2	138 20.0	20	5.0	22
E->W Trans	106	7 Sep.	0334	69 23.5	138 26.2			24

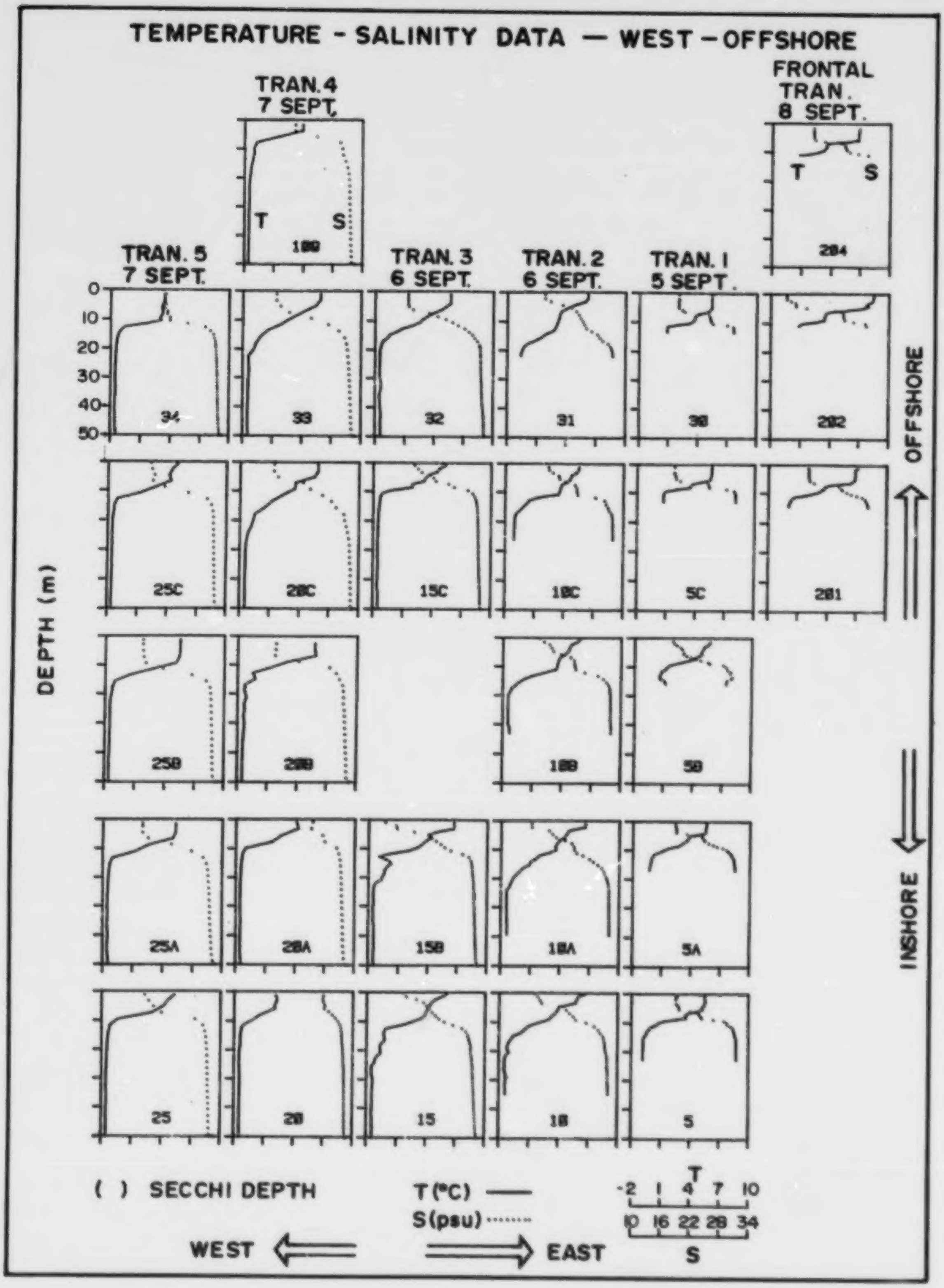
APPENDIX 1. Concluded.

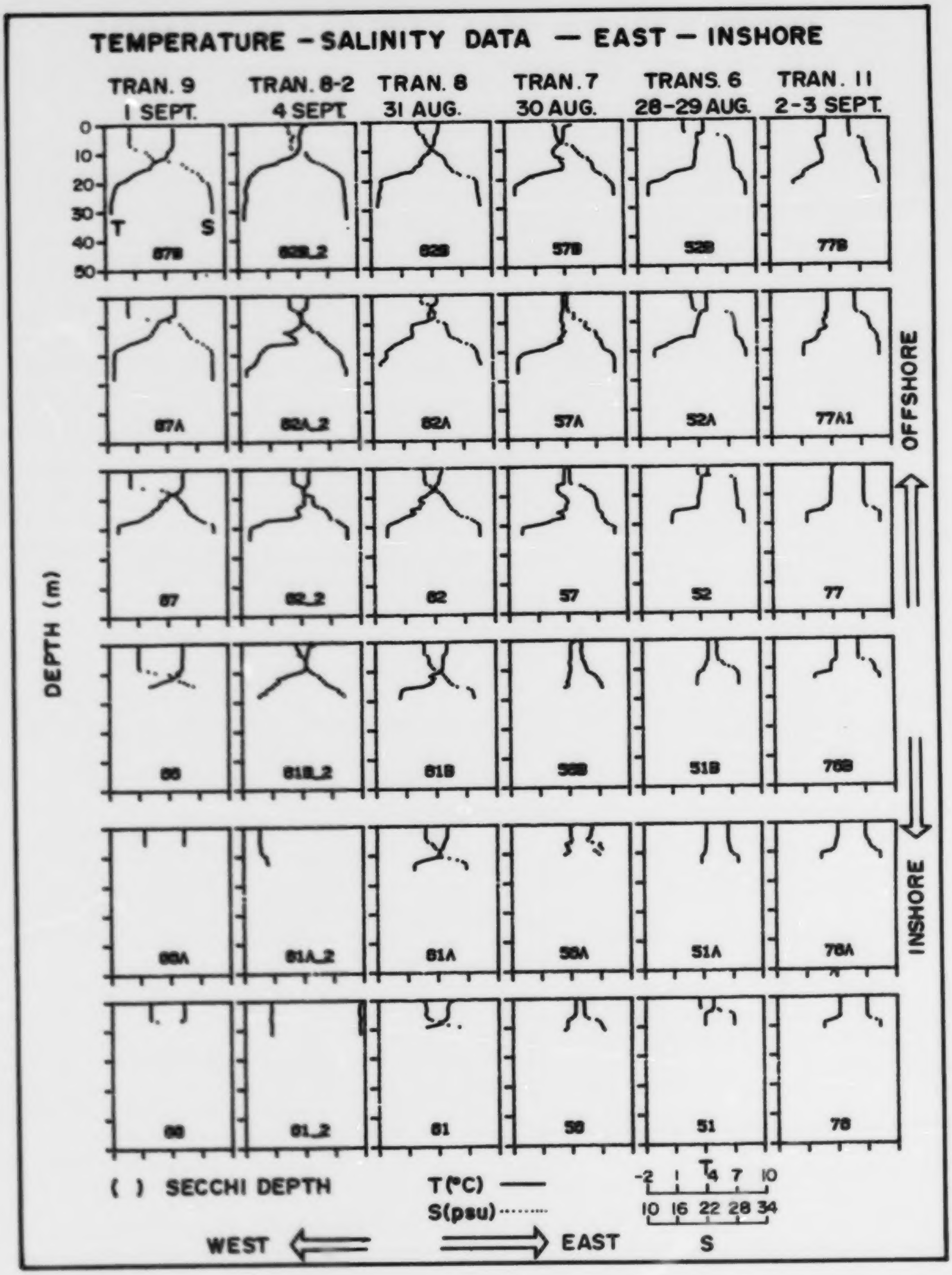
	108	7 Sep.	0734	69 24.8	138 44.0			22
Transect 4	17	7 Sep.	0813	69 24.1	138 51.9	20		10
	17A	7 Sep.	0828	69 26.1	138 47.4			35
	18	7 Sep.	0901	69 28.2	138 43.6			16
	18A	7 Sep.	0912	69 30.1	138 39.3			16
	19	7 Sep.	0929	69 32.0	138 35.0			47
	19A	7 Sep.	1004	69 34.1	138 31.0			74
	20	7 Sep.	1027	69 36.2	138 27.1			103
	20A	7 Sep.	1054	69 40.0	138 18.3			109
	20B	7 Sep.	1132	69 43.7	138 09.6			106
	20C	7 Sep.	1255	69 47.4	138 00.8			106
	33	7 Sep.	1323	69 51.2	137 52.0	112		105
S->N Trans	109	7 Sep.	1359	69 56.7	137 51.0	118		103
Transect 5	34	7 Sep.	1502	70 02.3	137 50.0	140	10.0	104
	25C	7 Sep.	1655	69 58.5	137 58.6			97
	25B	7 Sep.	1742	69 54.7	138 07.3			101
	25A	7 Sep.	1835	69 50.9	138 16.0			101
	25	7 Sep.	1859	69 47.1	138 24.7		5.0	102
	24A	7 Sep.	1958	69 45.1	138 28.9			104
	24	7 Sep.	2300	69 43.2	138 33.1		4.5	105
	23A	7 Sep.	2332	69 41.0	138 37.3			101
	23	8 Sep.	0136	69 39.2	138 41.5		5.0	103
	22A	8 Sep.	0407	69 37.6	138 45.7			47
	22	8 Sep.	0420	69 36.0	138 49.9	12	0.5	13
Frontal	201	8 Sep.	1938	69 25.1	136 40.3	6?		14
	202	8 Sep.	2036	69 25.1	136 26.4	4		11
	203	8 Sep.	2058	69 37.7	136 34.4	13		13
	204	8 Sep.	2138	69 36.3	136 30.0	11		11

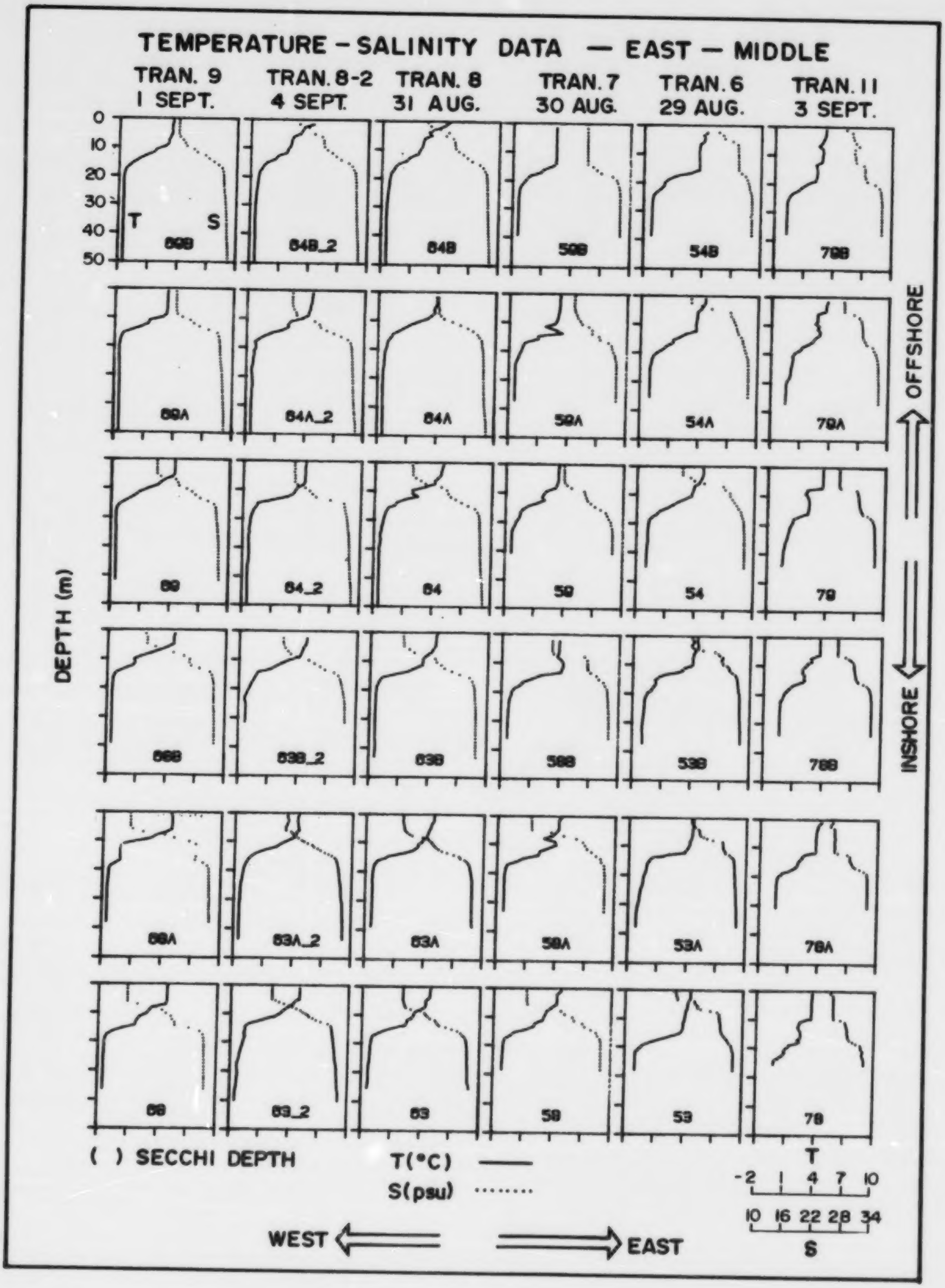
APPENDIX 2. Vertical profile plots of temperature, salinity, attenuance and density.



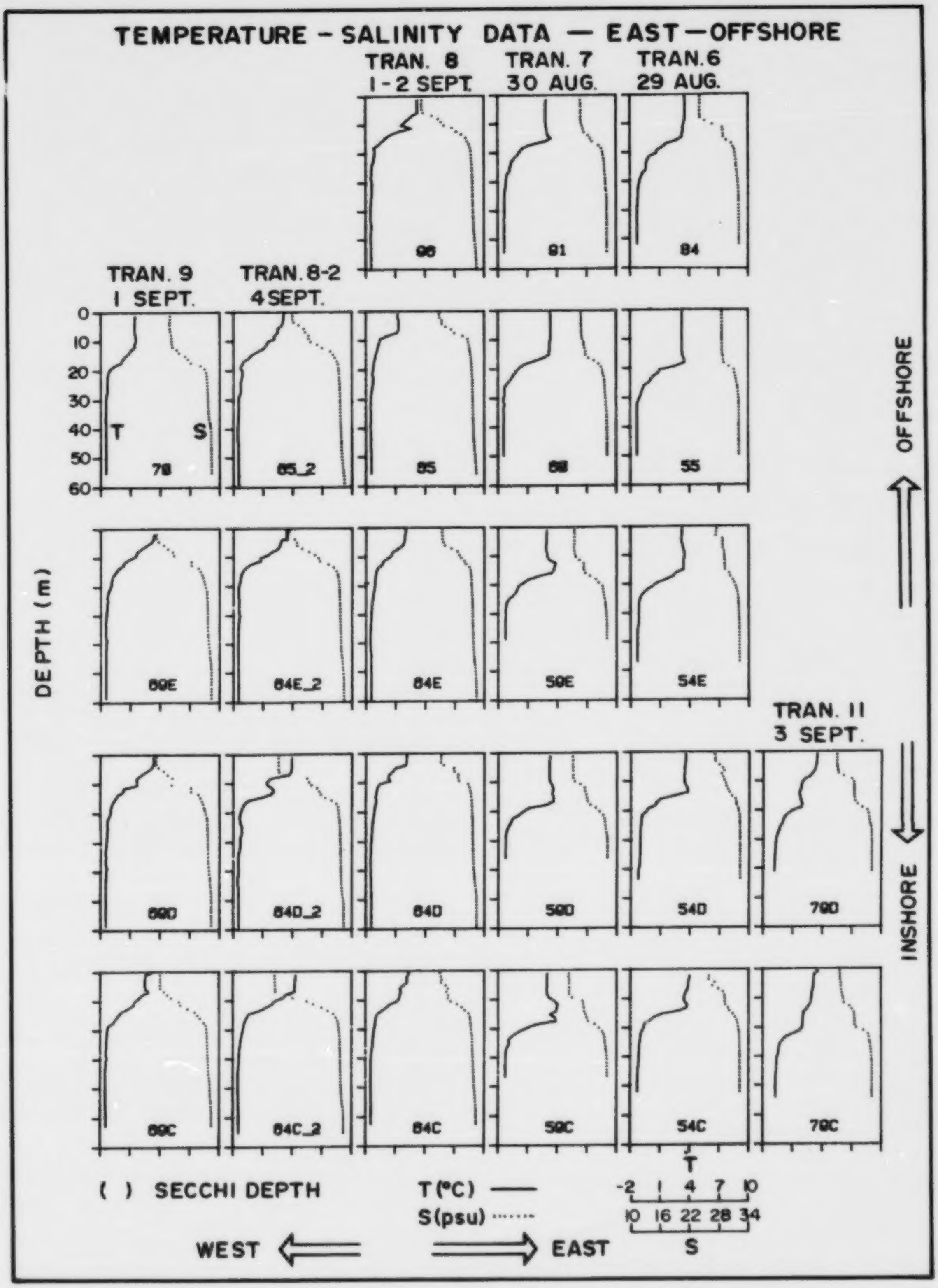
TEMPERATURE - SALINITY DATA — WEST — INSHORE

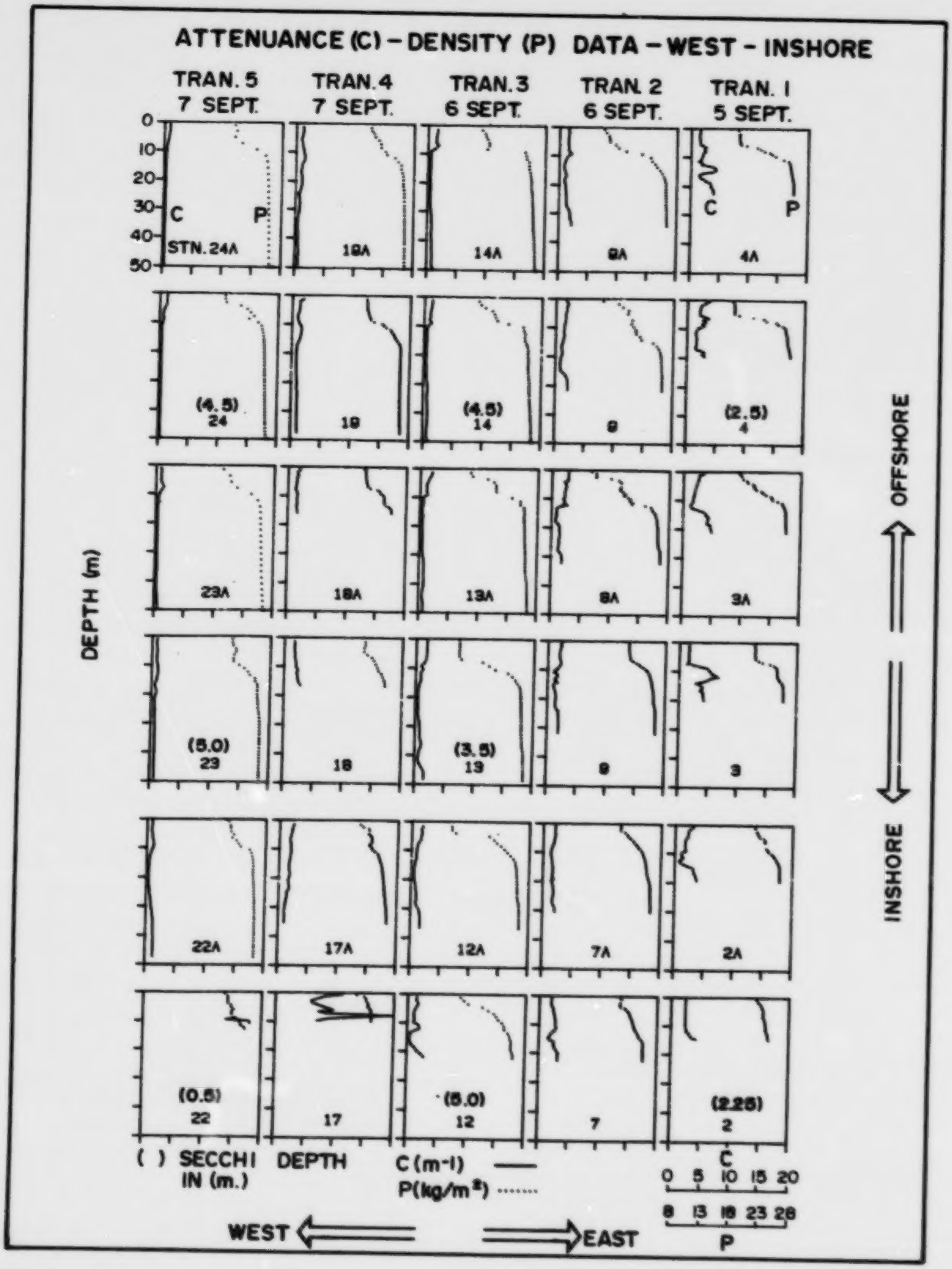

TEMPERATURE - SALINITY DATA — WEST - OFFSHORE
TRAN. 4
7 SEPT.
FRONTAL
TRAN.
8 SEPT.
T
S
180
204
TRAN. 5
7 SEPT.
TRAN. 3
6 SEPT.
TRAN. 2
6 SEPT.
TRAN. 1
5 SEPT.
0
10
20
30
40
50
34
33
32
31
30
202
25C
20C
15C
10C
5C
201
25B
20B
10B
5B
25A
20A
15B
10A
5A
25
20
15
10
5
DEPTH (m)
OFFSHORE
INSHORE
( ) SECCHI DEPTH
T(°C)
S(psu)
T
-2 1 4 7 10
10 16 22 28 34
S
WEST
EAST


TEMPERATURE - SALINITY DATA — EAST — INSHORE
TRAN. 9
1 SEPT.
TRAN. 8-2
4 SEPT.
TRAN. 8
31 AUG.
TRAN. 7
30 AUG.
TRANS. 6
28-29 AUG.
TRAN. 11
2-3 SEPT.
0
10
20
30
40
50
T
S
87B
82B_2
82B
57B
52B
77B
87A
82A_2
82A
57A
52A
77A1
87
82_2
82
57
52
77
86
81B_2
81B
56B
51B
76B
86A
81A_2
81A
56A
51A
76A
86
81_2
81
56
51
76
DEPTH (m)
OFFSHORE
INSHORE
( ) SECCHI DEPTH
T(°C)
S(psu)
-2
1
4
7
10
T
10
16
22
28
34
S
WEST
EAST



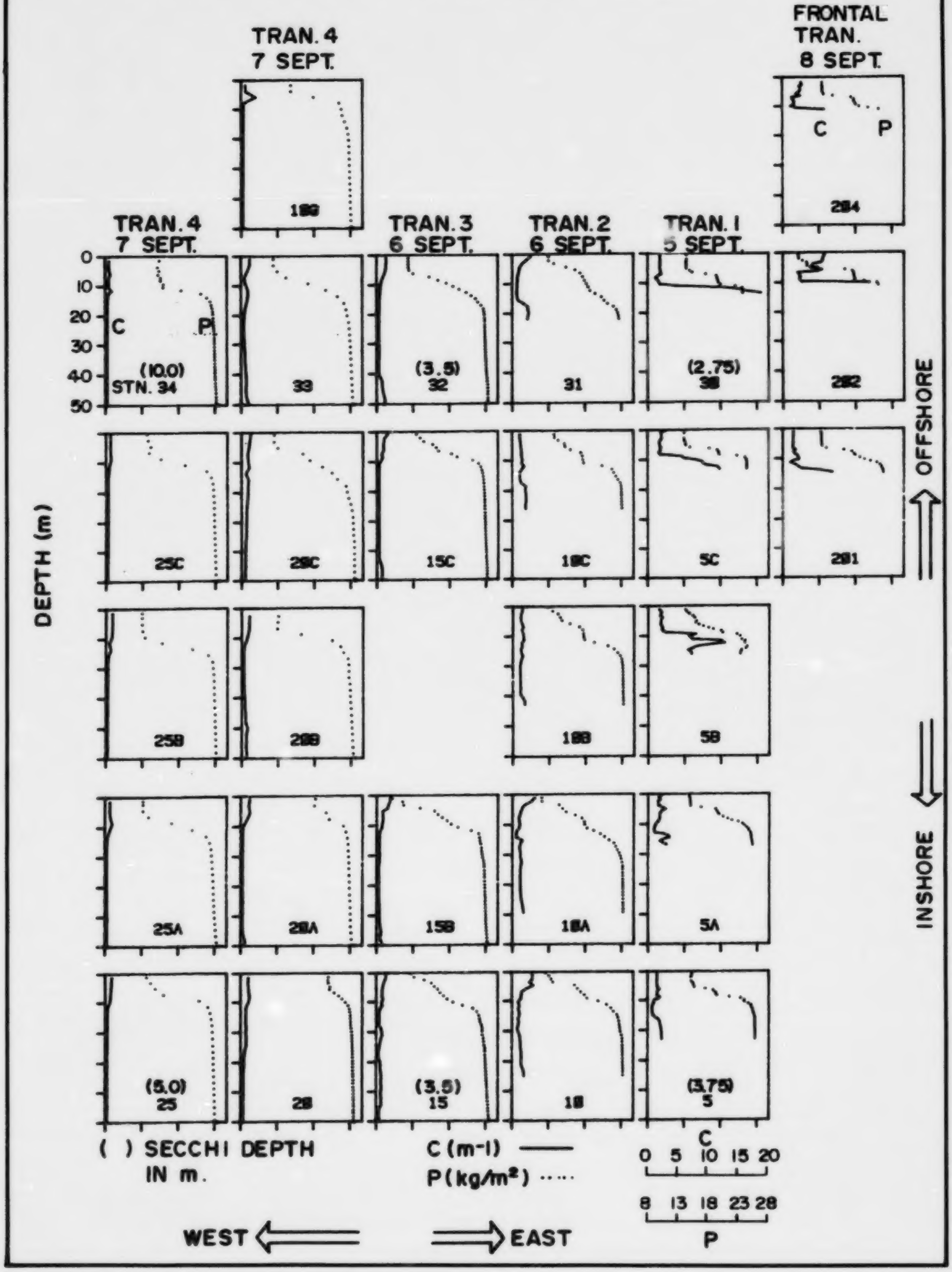
TEMPERATURE - SALINITY DATA — EAST — MIDDLE

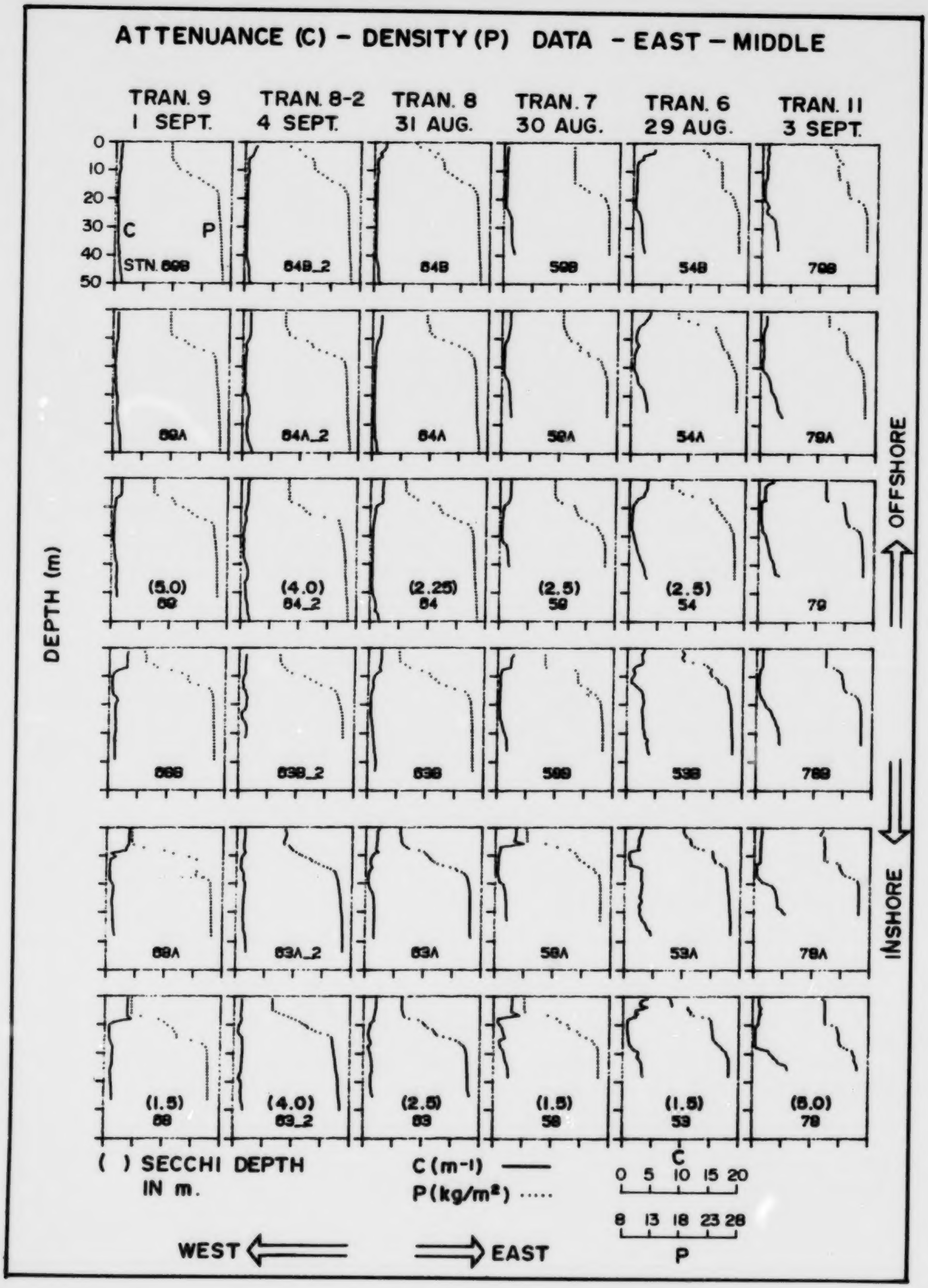

TEMPERATURE - SALINITY DATA — EAST—OFFSHORE
TRAN. 8
1-2 SEPT.
TRAN. 7
30 AUG.
TRAN. 6
29 AUG.
96
81
84
TRAN. 9
1 SEPT.
TRAN. 8-2
4 SEPT.
0
10
20
30
40
50
60
T
S
78
85_2
85
58
55
OFFSHORE
DEPTH (m)
89E
84E_2
84E
58E
54E
TRAN. 11
3 SEPT.
89D
84D_2
84D
58D
54D
79D
INSHORE
89C
84C_2
84C
58C
54C
79C
( ) SECCHI DEPTH
T(°C)
S(psu)
T
-2
1
4
7
10
10
16
22
28
34
S
WEST
EAST



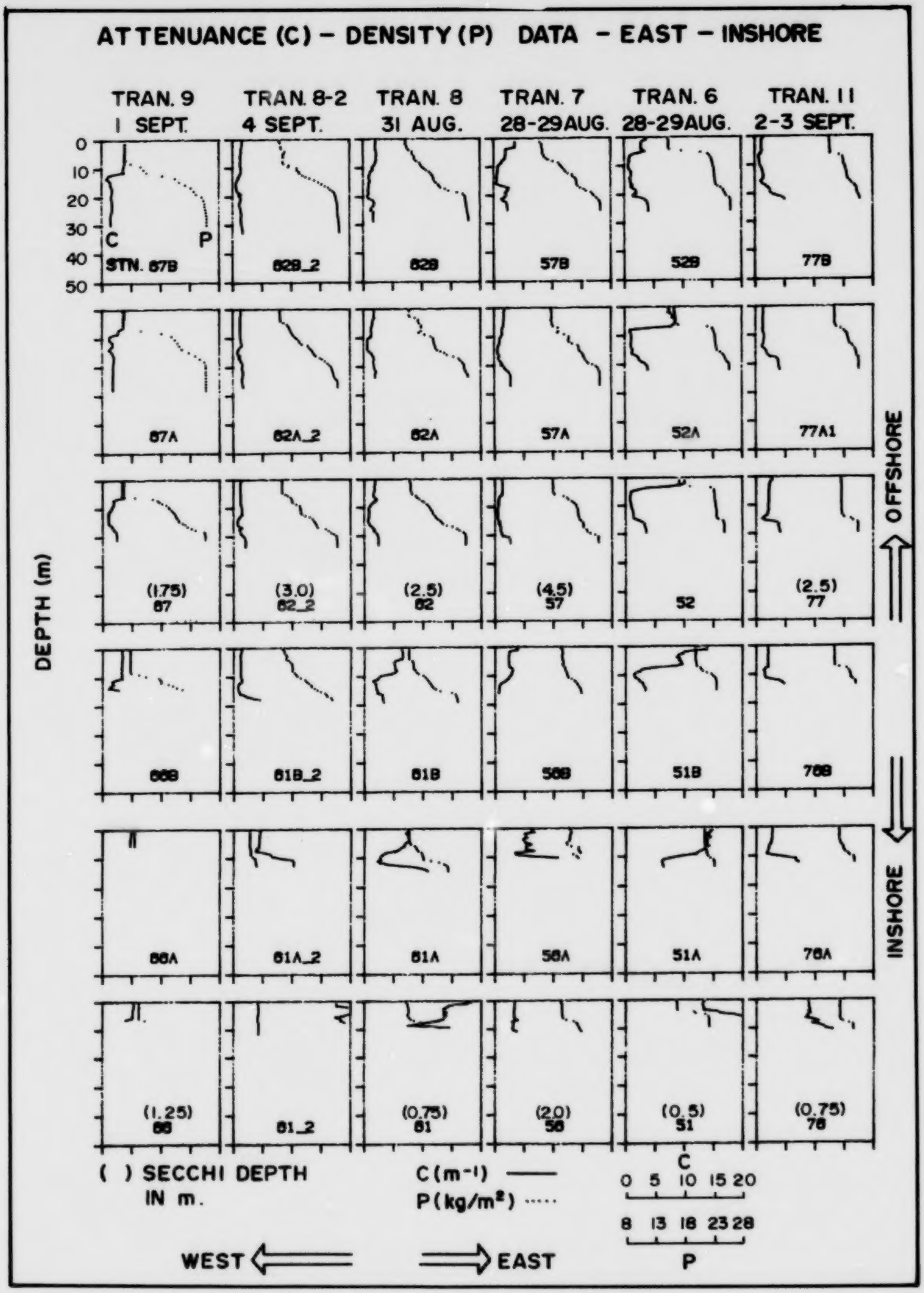
ATTENUANCE (C) - DENSITY (P) DATA - WEST - INSHORE

ATTENUANCE (C) - DENSITY (P) DATA - WEST - OFFSHORE



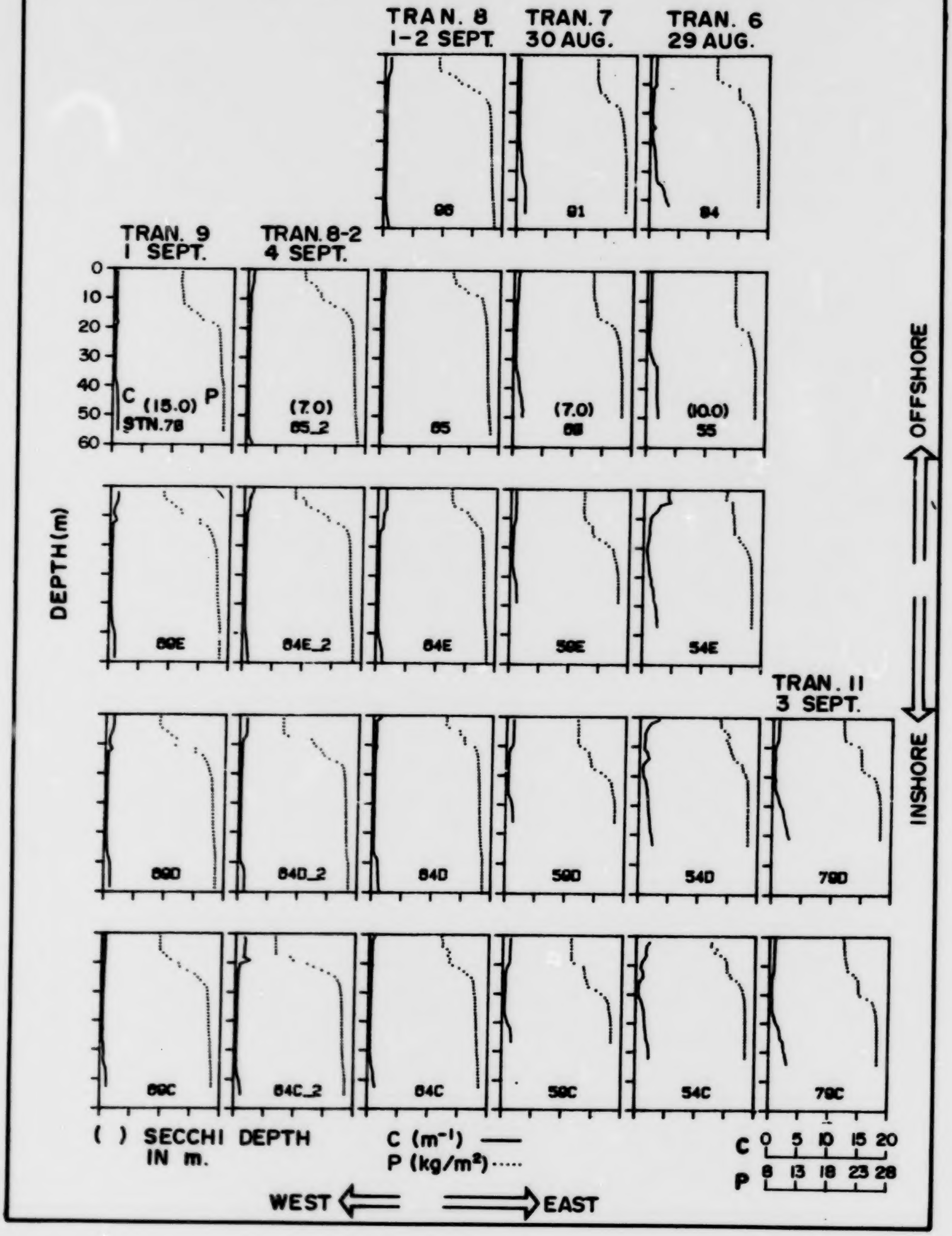


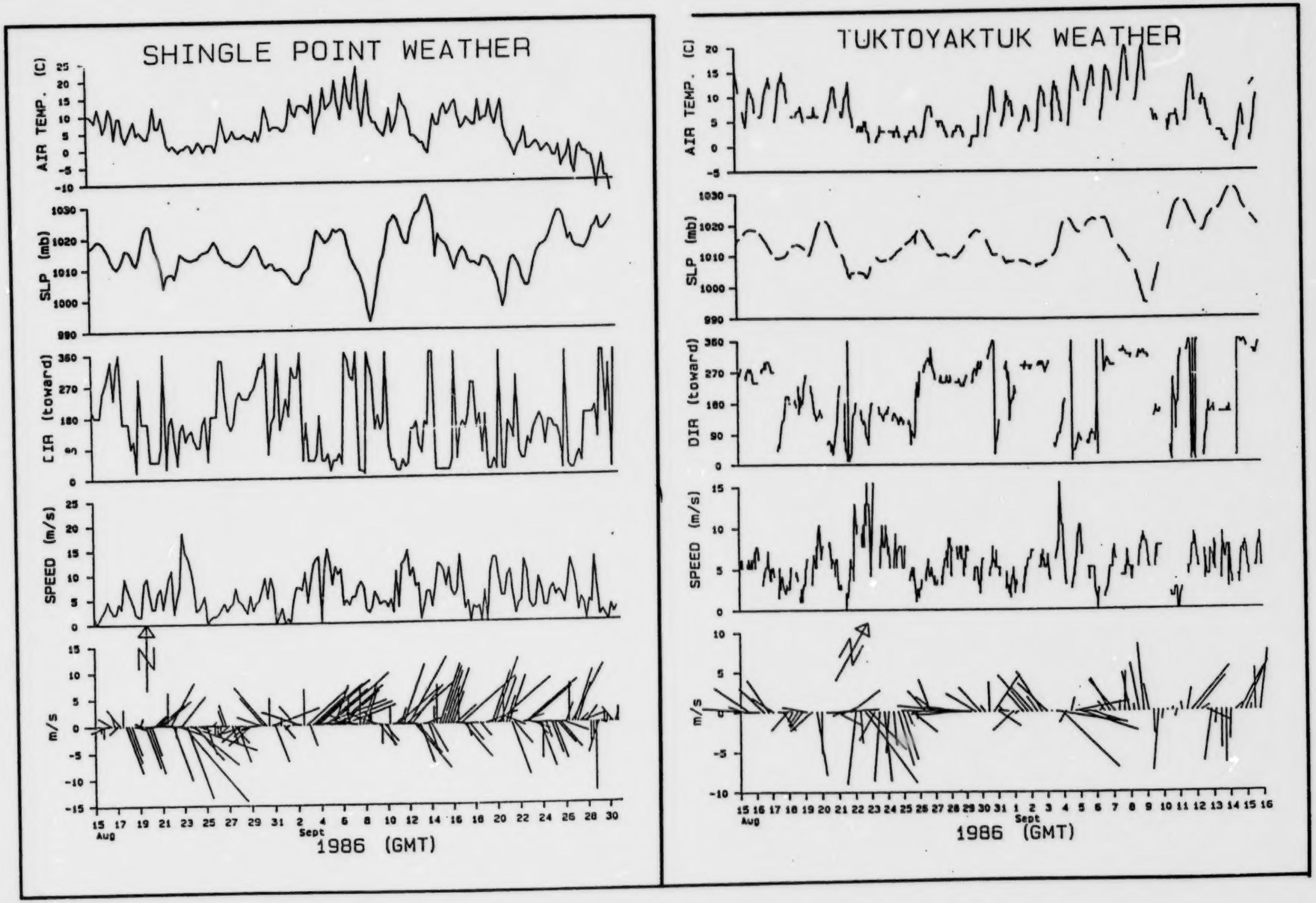
ATTENUANCE (C) - DENSITY (P) DATA - EAST - MIDDLE



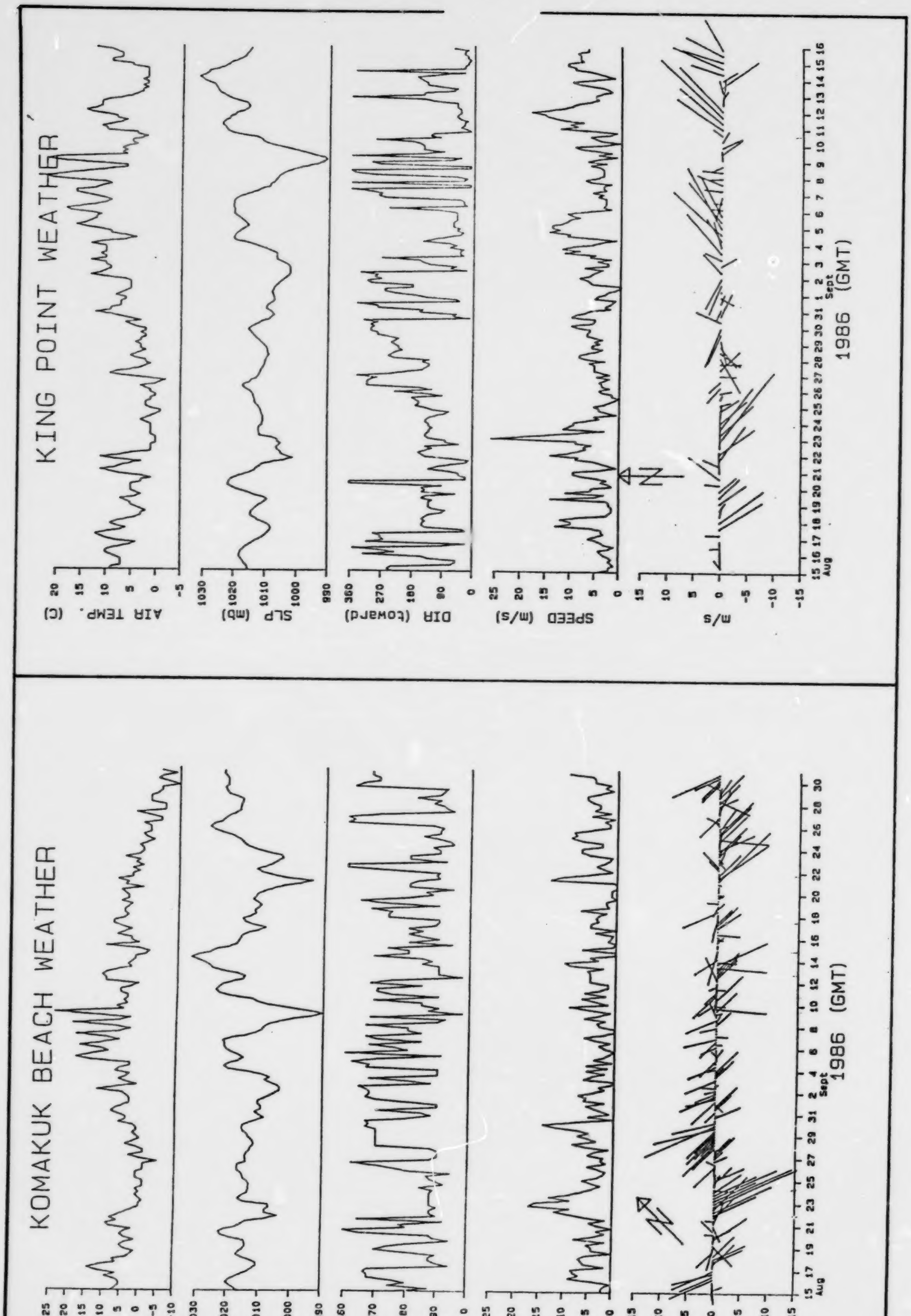
ATTENUANCE (C) - DENSITY (P) DATA - EAST - INSHORE

ATTENUANCE (C) - DENSITY (P) DATA - EAST - OFFSHORE

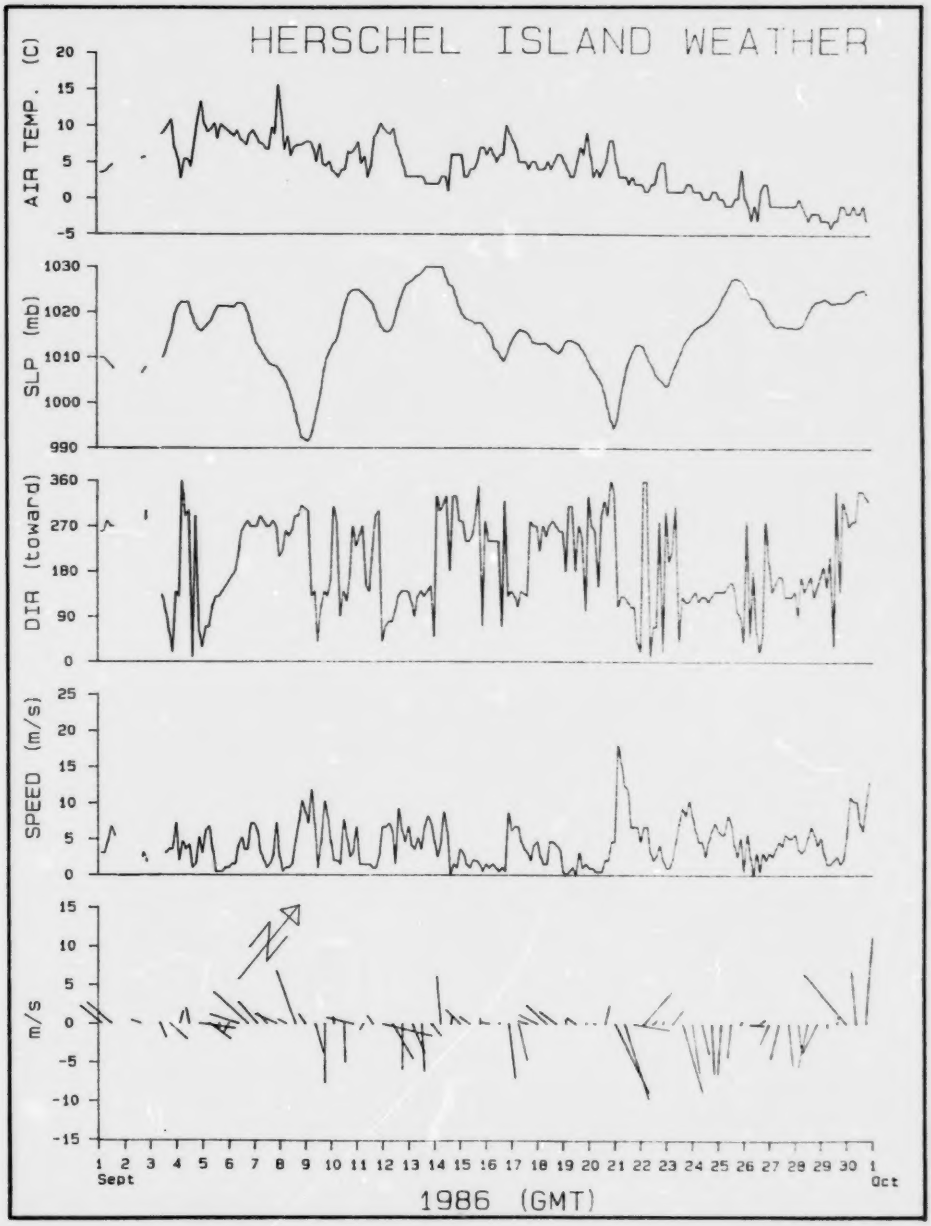




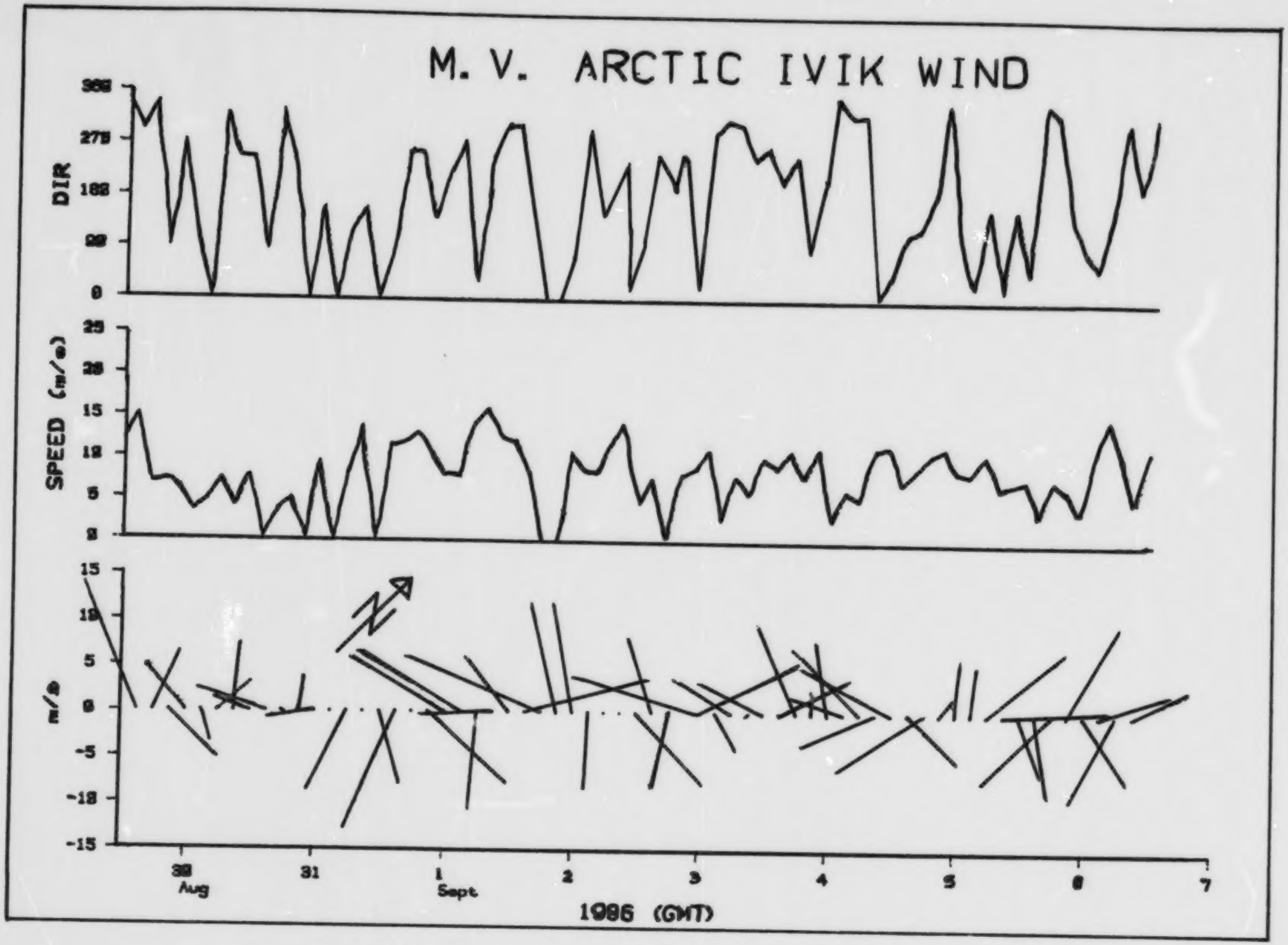
APPENDIX 3A. Plot of meteorological data from Shingle Point and Tuktoyaktuk.



APPENDIX 3B. Plot of meteorological data from Komakuk and King Point.



APPENDIX 3C. Plot of meteorological data from Herschel Island.



APPENDIX 3D. Plot of meteorological data from M.V. 'Arctic Ivik'.

APPENDIX 4. Summary of plankton samples collected in the Southeastern Beaufort Sea in August and September 1986.

		Date		Sample			Water			Water	Stratif-	Whales/
	Station	Mo	Da	Number	Type[a]	Depth (m)	Depth (m)	Area	Layers[b]	Mass[c]	ication[d]	Fronts[e]
Transect 1	2	9	5	1001	OB	10	14	Yukon	9	9	9	11
		9	5	2001	HS	1	14	Yukon	9	5	1	11
		9	5	3001	HD	3	14	Yukon	9	3	1	11
		9	5	3002	HD	5.2	14	Yukon	9	3	1	11
		9	5	3003	HD	8.5	14	Yukon	1	3	1	11
		9	5	3004	HD	11	14	Yukon	1	3	1	11
		9	5	3005	HD	12.5	14	Yukon	1	3	1	11
	3	9	5	1002	OB	18	21	Yukon	9	9	9	12
		9	5	2002	HS	1	21	Yukon	9	4	0	12
		9	5	3006	HD	2.1	21	Yukon	9	5	0	12
		9	5	3007	HD	8.5	21	Yukon	1	3	1	12
		9	5	3008	HD	11	21	Yukon	1	3	1	12
		9	5	3009	HD	14	21	Yukon	1	3	1	12
	4	9	5	1003	OB	16	24	Yukon	9	9	9	32
		9	5	2003	HS	1	24	Yukon	9	3	0	32
		9	5	3010	HD	3	24	Yukon	9	2	0	32
		9	5	3011	HD	9.4	24	Yukon	1	3	1	32
		9	5	3012	HD	15.5	24	Yukon	1	3	0	32
	5	9	5	1004	OB	21	24	Yukon	9	9	9	32
		9	5	2004	HS	1	24	Yukon	9	3	0	32
		9	5	3013	HD	3	24	Yukon	9	2	0	32
		9	5	3014	HD	10.1	24	Yukon	0	3	1	32
		9	5	3015	HD	16.8	24	Yukon	0	3	0	32
	30	9	5	1013	OB	12	14	Yukon	9	9	9	32
		9	5	2013	HS	1	14	Yukon	9	3	0	32
		9	5	3043	HD	3	14	Yukon	9	2	0	32
		9	5	3044	HD	10.7	14	Yukon	1	5	1	32
		9	5	3045	HD	12.5	14	Yukon	1	3	0	32
Transect 3	12	9	6	1005	OB	15	23	Yukon	9	9	9	32
		9	6	2005	HS	1	23	Yukon	9	3	0	32
		9	6	3016	HD	4	23	Yukon	9	2	0	32
		9	6	3017	HD	9.1	23	Yukon	1	3	1	32
		9	6	3018	HD	12.5	23	Yukon	0	3	1	32
	13	9	6	1006	OB	48	50.5	Yukon	9	9	9	32
		9	6	2006	HS	1	50.5	Yukon	9	3	0	32
		9	6	3019	HD	4	50.5	Yukon	0	2	0	32
		9	6	3020	HD	9	50.5	Yukon	1	3	1	32
		9	6	3021	HD	12.5	50.5	Yukon	0	3	1	32
		9	6	3022	HD	18.6	50.5	Yukon	0	3	0	32
	14	9	6	1007	OB	50	64	Yukon	9	9	9	32
		9	6	2007	HS	1	64	Yukon	9	3	0	32
		9	6	3023	HD	4.9	64	Yukon	9	5	1	32
		9	6	3024	HD	8.5	64	Yukon	1	5	1	32
		9	6	3025	HD	10.7	64	Yukon	1	3	1	32

APPENDIX 4. Continued

	Station	Date Mo	Date Da	Sample Number	Sample Type[a]	Sample Depth (m)	Water Depth (m)	Area	Layers[b]	Water Mass[c]	Stratification[d]	Whales/ Fronts[e]
Transect 3	14	9	6	3026	HD	20	64	Yukon	0	3	0	32
	15	9	6	1008	OB	50	56	Yukon	9	9	9	32
		9	6	2008	HS	1	56	Yukon	9	3	0	32
		9	6	3027	HD	4.9	56	Yukon	9	2	1	32
		9	6	3028	HD	8.2	56	Yukon	1	5	1	32
		9	6	3029	HD	10.7	56	Yukon	1	3	1	32
		9	6	3030	HD	18.6	56	Yukon	0	3	0	32
		9	6	3031	HD	39.6	56	Yukon	0	3	0	32
	32	9	6	1014	OB	50	57	Yukon	9	9	9	32
		9	6	2014	HS	1	57	Yukon	9	3	0	32
		9	6	3046	HD	3	57	Yukon	9	2	0	32
		9	6	3047	HD	8.2	57	Yukon	1	3	1	32
		9	6	3048	HD	23.5	57	Yukon	0	3	0	32
		9	6	3049	HD	39.9	57	Yukon	0	3	0	32
Transect 5	22	9	7	1009	OB	10	13	Yukon	9	9	9	32
		9	7	2009	HS	1	13	Yukon	9	3	0	32
		9	7	3032	HD	9.1	13	Yukon	1	3	1	32
	23	9	7	1010	OB	50	102	Yukon	9	9	9	32
		9	7	2010	HS	1	102	Yukon	9	4	0	32
		9	7	3033	HD	4.9	102	Yukon	9	5	0	32
		9	7	3034	HD	7.6	102	Yukon	1	5	0	32
		9	7	3035	HD	15.5	102	Yukon	0	3	1	32
	24	9	7	1011	OB	50	160	Yukon	9	9	9	32
		9	7	2011	HS	1	160	Yukon	9	3	0	32
		9	7	3036	HD	4	160	Yukon	9	2	0	32
		9	7	3037	HD	8.5	160	Yukon	1	3	1	32
	25	9	7	1012	OB	50	167	Yukon	9	9	9	32
		9	7	2012	HS	1	167	Yukon	9	3	0	32
		9	7	3038	HD	3	167	Yukon	9	2	1	32
		9	7	3039	HD	8.5	167	Yukon	1	3	1	32
		9	7	3040	HD	8.5	167	Yukon	1	3	1	32
		9	7	3041	HD	16.5	167	Yukon	0	3	0	32
		9	7	3042	HD	28.7	167	Yukon	0	3	0	32
	34	9	7	1015	OB	46	106	Yukon	9	9	9	32
		9	7	2015	HS	1	106	Yukon	9	3	0	32
		9	7	3050	HD	9.1	106	Yukon	1	2	0	32
Transect 6	51	8	29	1016	OB	12	10	Indust	9	9	9	32
		8	29	2016	HS	1	10	Indust	9	3	0	32
		8	29	3051	HD	8.7	10	Indust	9	5	0	32
	52	8	29	1017	OB	17	22	Indust	9	9	9	32
		8	29	2017	HS	1	22	Indust	9	3	0	32
		8	29	3052	HD	3	22	Indust	9	2	0	32
		8	29	3053	HD	5	22	Indust	9	5	1	32
	53	8	29	1018	OB	25	31	Indust	9	9	9	32
		8	29	2018	HS	1	31	Indust	9	3	0	32
		8	29	3054	HD	3.5	31	Indust	9	2	0	32
		8	29	3055	HD	17	31	Indust	9	3	1	32

APPENDIX 4. Continued

		Date		Sample			Water			Water	Stratif-	Whales/
	Station	Mo	Da	Number	Type[a]	Depth (m)	Depth (m)	Area	Layers[b]	Mass[c]	ication[d]	Fronts[e]
Transect 6	54	8	29	1019	OB	38	38	Indust	9	9	9	14
		8	29	2019	HS	1	38	Indust	9	3	0	14
		8	29	3056	HD	6	38	Indust	9	2	1	14
	55	8	29	1020	OB	50	52	Indust	9	9	9	14
		8	29	2020	HS	1	52	Indust	9	5	0	14
		8	29	3057	HD	20	52	Indust	9	3	1	14
Transect 7	56	8	30	1021	OB	10	11	Indust	9	9	9	32
		8	30	3058	HD	6	11	Indust	9	2	0	32
	57	8	30	1022	OB	22	26	Indust	9	9	9	32
		8	30	2022	HS	1	26	Indust	9	3	0	32
		8	30	3059	HD	7	26	Indust	9	2	1	32
	58	8	30	1023	OB	28	30	Indust	9	9	9	32
		8	30	2023	HS	1	30	Indust	9	3	0	32
		8	30	3060	HD	12	30	Indust	9	3	1	32
	59	8	30	1024	OB	30	36	Indust	9	9	9	32
		8	30	2024	HS	1	36	Indust	9	3	0	32
		8	30	3061	HD	7	36	Indust	9	5	1	32
	60	8	30	1025	OB	47	49	Indust	9	9	9	12
		8	30	2025	HS	1	49	Indust	9	5	0	12
		8	30	3062	HD	17	49	Indust	9	3	1	12
Transect 8	161	8	31	1036	OB	8	10	Indust	9	9	9	32
		8	31	2036	HS	1	10	Indust	9	3	0	32
		8	31	3078	HD	8	10	Indust	9	2	1	32
	162	8	31	1037	OB	24	26	Indust	9	9	9	32
		8	31	2037	HS	1	26	Indust	9	3	0	32
		8	31	3079	HD	10	26	Indust	9	5	1	32
	163	8	31	1038	OB	35	44	Indust	9	9	9	32
		8	31	2038	HS	1	44	Indust	9	3	0	32
		8	31	3080	HD	15	44	Indust	9	3	1	32
	164	8	31	1039	OB	48	52	Indust	9	9	9	32
		8	31	2039	HS	1	52	Indust	9	3	0	32
		8	31	3081	HD	12	52	Indust	1	5	1	32
		8	31	3082	HD	20	52	Indust	0	3	0	32
	165	9	1	1040	OB	50	68	Indust	9	9	9	32
		9	1	2040	HS	1	68	Indust	9	5	0	32
		9	1	3083	HD	13	68	Indust	1	3	0	32
	261	9	5	1041	OB	9	10	Indust	9	9	9	32
		9	5	2049	HS	1	10	Indust	9	1	0	32
	262	9	4	1042	OB	24	26	Indust	9	9	9	32
		9	4	2050	HS	1	26	Indust	9	3	0	32
		9	4	3092	HD	5	26	Indust	9	2	0	32
		9	4	3093	HD	8.5	26	Indust	1	2	0	32
		9	4	3094	HD	12.5	26	Indust	1	5	1	32
		9	4	3095	HD	18.6	26	Indust	0	3	1	32
	263	9	4	1043	OB	38	44	Indust	9	9	9	32
		9	4	2051	HS	1	44	Indust	9	3	0	32
		9	4	3096	HD	4	44	Indust	9	2	0	32

APPENDIX 4. Continued

	Station	Date		Sample			Water Depth (m)	Area	Layers^b	Water Mass^c	Stratification^d	Whales/ Fronts^e
		Mo	Da	Number	Type^a	Depth (m)						
Transect 8	263	9	4	3097	HD	8.5	44	Indust	1	5	1	32
		9	4	3098	HD	23.5	44	Indust	0	3	0	32
	264	9	4	1044	OB	50	52	Indust	9	9	9	32
		9	4	2052	HS	1	52	Indust	9	3	0	32
		9	4	3099	HD	5	52	Indust	9	2	0	32
		9	4	3100	HD	9	52	Indust	1	2	1	32
		9	4	3101	HD	14	52	Indust	1	3	1	32
	265	9	4	1045	OB	65	68	Indust	9	9	9	32
		9	4	1046	OB	50	68	Indust	9	9	9	32
		9	4	2053	HS	1	68	Indust	9	4	0	32
		9	4	3102	HD	6.7	68	Indust	0	5	1	32
		9	4	3103	HD	12	68	Indust	1	3	1	32
		9	4	3104	HD	19.5	68	Indust	0	3	0	32
Transect 9	66	9	1	1026	OB	7	10	Indust	9	9	9	32
		9	1	2026	HS	1	10	Indust	9	3	0	32
		9	1	3063	HD	6	10	Indust	9	2	0	32
	67	9	1	1027	OB	20	24	Indust	9	9	9	32
		9	1	2027	HS	1	24	Indust	9	3	0	32
		9	1	3064	HD	11	24	Indust	1	5	1	32
	68	9	1	1028	OB	33	38	Indust	9	9	9	32
		9	1	2028	HS	1	38	Indust	9	3	0	32
		9	1	3065	HD	14	38	Indust	1	3	1	32
	69	9	1	1029	OB	43	44	Indust	9	9	9	32
		9	1	2029	HS	1	44	Indust	9	3	0	32
		9	1	3066	HD	14	44	Indust	1	3	1	32
	70	9	1	1030	OB	50	58	Indust	9	9	9	32
		9	1	2030	HS	1	58	Indust	9	5	0	32
		9	1	3067	HD	16	58	Indust	1	3	1	32
Transect 11	76	9	2	1031	OB	9	11.5	Tuk	9	9	9	32
		9	2	2031	HS	1	11.5	Tuk	9	4	0	32
	77	9	3	1032	OB	19	20.5	Tuk	9	9	9	32
		9	2	2032	HS	1	20.5	Tuk	9	4	0	32
		9	3	3068	HD	8.5	20.5	Tuk	1	5	0	32
		9	3	3069	HD	13	20.5	Tuk	1	5	1	32
	78	9	3	1033	OB	25	26.5	Tuk	9	9	9	32
		9	3	2033	HS	1	26.5	Tuk	9	3	0	32
		9	3	3070	HD	16	26.5	Tuk	1	5	1	32
	79	9	3	1034	OB	34	36	Tuk	9	9	9	13
		9	3	2034	HS	1	36	Tuk	9	3	0	13
		9	3	3071	HD	4	36	Tuk	9	2	0	13
		9	3	3072	HD	13	36	Tuk	1	3	1	13
		9	3	3073	HD	21	36	Tuk	0	3	0	13
	79.3	9	3	1035	OB	40	43	Tuk	9	9	9	14
		9	3	2035	HS	1	43	Tuk	9	4	0	14
		9	3	3074	HD	5	43	Tuk	0	5	0	14
		9	3	3075	HD	10.5	43	Tuk	1	3	0	14
		9	3	3076	HD	25	43	Tuk	0	3	0	14

APPENDIX 4. Continued

	Station	Date		Sample			Water Depth (m)	Area	Layers[b]	Water Mass[c]	Stratification[d]	Whales/ Fronts[e]
		Mo	Da	Number	Type[a]	Depth (m)						
Transect 11	79.3	9	3	3077	HD	33	43	Tuk	0	3	0	14
Transect 17	201	9	8	2041	HS	1	14.5	Front	9	9	0	21
		9	8	2042	HS	1	14.5	Front	9	9	0	21
		9	8	3084	HD	9.4	14.5	Front	1	3	1	21
		9	8	3085	HD	9.5	14.5	Front	1	3	1	21
	202	9	8	2043	HS	1	11	Front	9	9	0	22
		9	8	2044	HS	1	11	Front	9	9	0	22
		9	8	2045	HS	1	11	Front	9	9	0	21
		9	8	2046	HS	1	11	Front	9	9	0	21
		9	8	3086	HD	10	11	Front	1	3	0	21
		9	8	3087	HD	10	11	Front	1	3	1	22
		9	8	3088	HD	10	11	Front	1	3	1	22
		9	8	3089	HD	10	11	Front	1	3	0	21
	203	9	8	2047	HS	1	14.5	Front	9	9	0	22
		9	8	2048	HS	1	14.5	Front	9	9	0	22
		9	8	3090	HD	10	14.5	Front	1	3	1	22
		9	8	3091	HD	10	14.5	Front	1	3	1	22

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[a] OB = Oblique tows, HS = Horizontal tows at Surface, HD = Horizontal tows at depth.

[b] 1 = Sample taken inside layers of concentrated zooplankton as shown on the echosounder,
2 = Sample taken outside layers,
9 = Oblique or surface tow or echosounder not functioning.

[c] 1 = Intense Plume, 2 = Intense/Diffuse Plume, 3= Diffuse Plume, 4 = Diffuse/Arctic,
5 = Arctic Water.

[d] 1= Strong vertical density gradients, 2 = Weak vertical density gradients,
9 = Not applicable to surface and oblique tows.

[e] 11 = Whales definitely feeing near ship, 12 = Whales probably feeding near ship,
13 = Whales within 1 km of ship, 14 = Whales > 1 km from ship, 32= No whales visible from ship
21 = Samples taken on turbid side of front, 22= Samples taken on clear side of front.

APPENDIX 5. Biomass (mg/m3) of major groups of zooplankton collected in the souteastern Beaufort Sea in August and September 1986.

	Station	Sample Number	Hydrozoa	Ctenophora	Pteropoda	Chaetognatha	Pisces	Mysidacea	Euphausiacea	Decapoda	Copepoda	Hyperiidea	Gammaridea	Other	Total
Transect 1	2	1001	7.5	1.2	3.6	5.6	0.4	8.2	39.2	1.3	706.2	2.4	0.2	0.6	776.4
		2001	2.7	0.0	4.8	0.4	0.0	0.2	0.2	0.0	338.8	0.2	0.2	0.0	347.5
		3001	4.0	0.0	2.3	3.5	0.0	4.5	2.5	0.9	1523.3	1.7	0.0	0.0	1542.9
		3002	8.5	0.6	2.3	3.7	0.9	6.9	3.6	1.4	1437.7	1.1	0.1	2.4	1469.0
		3003	23.3	0.8	0.7	10.9	1.1	10.4	31.1	4.4	1350.5	4.4	0.1	0.7	1438.1
		3004	21.1	2.8	0.6	20.5	6.4	19.5	45.0	4.0	590.7	5.5	0.3	2.0	718.4
		3005	20.8	0.3	2.2	9.6	6.2	26.4	38.4	4.4	999.5	4.7	0.4	1.6	1114.4
	3	1002	10.0	2.9	0.2	27.6	1.8	29.1	92.4	1.8	275.3	5.7	1.6	6.4	454.8
		2002	2.3	1.5	0.2	0.1	0.0	0.0	0.0	0.0	41.5	0.0	0.0	0.0	45.7
		3006	4.8	1.7	0.1	0.0	0.4	0.1	0.0	0.2	628.6	1.1	0.1	2.9	640.0
		3007	46.9	12.0	0.4	22.7	0.0	7.5	29.9	1.9	158.8	5.6	2.0	6.0	293.6
		3008	3.3	0.3	0.0	30.6	1.7	7.7	82.8	0.6	151.8	3.8	0.8	3.1	286.5
		3009	100.2	8.3	0.2	63.1	0.0	46.2	46.1	4.9	492.4	3.6	2.3	3.1	770.5
	4	1003	44.5	7.3	1.5	11.1	5.6	13.2	0.0	1.6	71.3	14.4	0.9	2.9	174.3
		2003	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.1	1.5
		3010	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	1.9
		3011	13.5	0.8	0.7	33.4	1.4	14.1	0.0	0.5	57.4	10.9	2.6	0.0	135.4
		3012	68.2	7.4	0.6	23.3	32.4	94.1	2.3	1.1	324.9	5.0	1.5	5.7	566.5
	5	1004	29.7	10.9	0.4	10.9	0.4	8.7	9.2	0.8	41.2	2.3	2.4	2.2	119.0
		2004	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	1.1
		3013	3.6	5.9	1.5	0.1	0.0	0.0	2.4	1.9	1.2	1.1	0.4	1.9	20.2
		3014	41.0	0.6	2.1	1.0	4.6	1.5	4.9	1.2	4.3	1.6	2.6	0.3	65.8
		3015	7.2	1.9	0.2	20.7	6.4	12.9	7.5	0.1	45.1	2.4	1.2	3.0	108.7
	30	1013	9.5	3.2	0.4	0.5	8.7	29.0	6.4	0.0	31.0	4.4	0.1	0.6	93.8
		2013	0.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	1.1
		3043	1.3	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.2	4.4
		3044	17.1	2.2	0.0	0.8	30.4	12.6	12.9	0.5	7.0	6.5	0.0	0.9	90.9
		3045	4.8	0.4	0.1	0.9	109.7	81.0	13.8	0.1	60.5	3.1	0.1	1.0	275.5
Transect 3	12	1005	6.0	0.2	2.9	0.3	0.0	0.0	4.6	0.7	70.5	7.4	0.2	0.6	93.2
		2005	0.0	0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.4	2.0	0.0	2.0	5.5
		3016	2.0	1.0	3.0	0.0	0.0	0.0	0.0	0.5	0.9	6.6	0.0	1.0	15.0
		3017	1.6	0.2	2.0	0.1	9.0	0.1	0.6	1.1	22.3	8.6	0.5	0.6	46.7
		3018	4.9	0.0	1.0	0.5	4.1	1.7	13.0	1.5	105.7	8.8	1.8	4.3	147.3
	13	1006	19.3	6.8	1.5	0.9	5.5	0.0	2.3	1.0	104.7	5.6	1.0	1.8	150.3
		2006	0.8	2.6	0.3	0.1	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.2	7.2

APPENDIX 5. Continued

	Stat.	Samp	Hydr	Cteno	Ptero	Chaet	Fish	Mysid	Eupha	Dec	Copep	Hyper	Gamm	Other	Total
Transect 3	13	3019	2.0	1.1	2.8	0.0	0.4	0.0	0.0	0.9	0.1	0.7	0.0	0.3	8.3
		3020	8.4	2.6	2.2	0.0	0.0	0.0	0.0	0.2	0.2	8.1	1.1	0.3	23.1
		3021	5.2	1.0	1.1	0.3	0.4	0.0	0.0	1.0	4.6	6.7	1.8	1.2	23.2
		3022	2.4	0.3	0.9	1.0	3.4	0.0	0.0	0.2	15.1	2.6	0.7	0.3	26.9
	14	1007	18.8	1.0	2.1	1.0	0.0	0.0	3.0	0.2	114.7	1.2	0.6	5.2	147.7
		2007	1.2	1.9	0.1	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.2	4.1
		3023	0.2	0.0	0.4	0.0	0.0	0.0	0.0	5.2	73.0	0.0	0.0	1.2	80.1
		3024	10.9	9.0	2.2	0.3	0.4	0.0	0.1	1.5	14.7	7.2	0.5	3.2	50.1
		3025	1.9	2.9	5.5	0.3	8.0	0.0	0.0	0.4	14.0	2.9	1.9	1.7	39.6
		3026	12.6	0.2	2.3	1.3	0.0	0.0	0.0	1.4	13.2	2.4	0.6	0.4	34.2
	15	1008	3.2	1.0	0.7	1.1	1.8	0.0	7.8	0.5	42.7	7.6	0.1	2.5	69.1
		2008	1.2	19.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	20.8
		3027	10.2	4.8	0.0	0.0	0.2	0.0	0.0	0.5	1.4	0.0	0.3	2.0	19.4
		3028	4.7	0.3	1.5	0.0	0.7	0.0	0.0	3.7	250.0	10.7	0.1	0.0	271.6
		3029	30.4	3.1	3.9	0.0	0.7	0.0	0.0	1.0	18.7	3.4	0.1	0.6	61.9
		3030	10.7	1.9	1.9	2.0	2.1	0.0	0.0	0.0	32.1	3.3	0.3	2.8	57.1
		3031	6.8	1.3	0.5	2.3	4.4	0.0	8.8	0.1	91.1	1.1	0.3	5.3	122.1
	32	1014	6.0	0.5	0.6	4.1	0.0	0.0	1.4	0.4	120.6	0.6	0.4	3.3	138.1
		2014	0.0	37.5	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.2	0.2	38.4
		3046	13.6	2.3	0.0	0.1	0.0	0.0	0.0	0.8	1.0	0.0	0.5	1.2	19.6
		3047	1.9	2.2	3.6	1.0	1.7	0.0	0.0	0.2	36.0	0.2	0.1	1.4	48.3
		3048	12.3	2.8	0.3	1.5	3.8	0.0	0.0	0.1	20.5	0.3	0.1	1.1	42.8
		3049	3.1	1.6	0.3	1.5	0.0	0.0	0.0	0.1	57.1	1.1	0.0	2.0	66.8
Transect 5	22	1009	2.7	0.2	0.3	9.6	7.3	13.0	0.5	0.7	115.9	1.0	1.4	1.4	154.1
		2009	63.6	0.0	7.1	1.5	9.7	0.2	0.6	0.0	5.1	0.1	0.0	0.6	88.6
		3032	17.6	0.3	4.0	11.0	7.2	3.8	1.3	7.7	192.9	3.8	5.3	4.2	259.1
	23	1010	5.8	0.2	1.1	2.6	0.0	0.0	0.0	0.6	102.5	1.5	0.3	4.3	118.9
		2010	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6
		3033	2.5	1.7	8.8	0.5	10.7	0.0	0.0	4.6	22.5	11.3	0.1	1.3	63.8
		3034	6.2	0.2	2.1	3.0	0.0	0.0	0.0	0.7	80.0	2.5	0.0	0.7	95.4
		3035	9.4	0.5	1.9	2.3	1.9	0.0	0.0	0.5	19.6	3.7	0.6	1.2	41.7
	24	1011	23.2	7.5	0.2	4.1	0.0	0.0	0.0	0.9	8.0	0.5	0.0	0.1	44.7
		2011	0.9	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.3	7.7
		3036	13.2	12.7	6.3	0.0	0.6	0.0	0.0	2.7	1.3	5.0	0.0	0.1	41.7
		3037	5.9	17.1	0.8	0.9	0.0	0.0	0.0	0.0	7.9	2.8	0.2	0.3	35.9
	25	1012	17.7	13.4	0.7	3.1	0.0	0.0	0.0	0.0	7.1	1.0	0.0	2.2	45.2
		2012	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.8
		3038	1.5	8.3	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	2.0	12.0
		3039	3.9	38.0	2.9	0.6	0.0	0.0	0.0	0.6	0.5	0.5	0.0	8.6	55.5
		3040	1.6	29.1	6.1	0.2	0.0	0.0	0.0	0.2	0.3	2.2	1.3	12.4	53.3
		3041	8.5	33.6	0.4	1.0	1.4	0.0	0.0	0.2	0.8	0.0	0.0	7.5	53.5
		3042	23.7	16.1	1.9	1.6	0.0	0.0	0.0	0.2	2.9	0.3	0.0	6.5	53.1
	34	1015	3.0	0.8	0.1	1.6	0.0	0.0	0.0	0.0	8.7	2.2	0.7	0.3	17.4
		2015	0.5	0.4	0.0	0.0	0.0	0.0	0.2	0.2	4.7	0.4	1.0	0.2	7.5
		3050	3.0	18.4	0.2	0.1	10.8	0.0	0.0	0.0	0.1	2.1	0.5	1.8	36.8
Transect 6	51	1016	14.9	8.5	0.5	1.8	7.7	14.9	0.0	0.0	7.9	0.0	0.0	2.7	59.0
		2016	9.2	4.2	0.0	1.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0
		3051	45.9	8.5	0.2	11.6	2.4	44.5	0.5	0.2	20.0	0.3	1.7	5.7	141.6

APPENDIX 5. Continued

	Stat.	Samp	Hydr	Cteno	Ptero	Chaet	Fish	Mysid	Eupha	Dec	Copep	Hyper	Gamm	Other	Total
Transect 6	52	1017	9.4	3.7	1.6	0.3	9.1	0.0	0.0	1.1	1.4	0.4	0.0	1.2	28.2
		2017	2.3	1.0	0.0	0.4	0.0	0.2	0.0	0.0	0.4	0.0	0.0	0.2	4.5
		3052	1.8	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.2	2.7
		3053	3.1	1.6	0.2	0.0	0.4	0.0	0.0	0.0	0.5	0.0	0.0	0.8	6.7
	53	1018	37.8	4.9	0.6	4.2	30.0	2.5	0.0	4.8	90.9	0.4	0.7	13.6	190.6
		2018	1.7	1.6	0.3	0.0	2.0	0.0	0.0	0.1	0.3	0.0	0.0	3.6	9.6
		3054	0.8	0.0	0.0	0.1	0.4	0.0	0.0	0.0	1.5	0.0	0.0	0.4	3.3
		3055	5.2	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	1.4	7.7
	54	1019	33.0	25.1	1.1	7.5	12.0	0.0	0.0	2.7	163.9	0.5	0.0	13.6	259.5
		2019	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2
		3056	12.3	0.0	10.8	0.0	9.5	0.0	0.0	0.0	0.8	0.0	0.0	0.8	34.3
	55	1020	16.6	28.2	0.8	5.7	0.0	0.9	0.0	0.1	224.4	0.5	0.1	5.0	282.3
		2020	2.9	0.7	0.4	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.1	0.0	5.0
		3057	12.6	1.7	6.5	1.5	16.3	0.0	0.0	0.6	96.9	0.5	0.0	2.2	138.9
Transect 7	56	1021	23.3	4.9	7.1	0.0	4.9	0.0	0.0	0.8	2.1	0.3	0.0	1.3	44.7
		3058	10.4	1.6	2.2	0.3	12.2	0.1	0.0	0.7	2.1	0.2	0.0	2.0	31.7
	57	1022	21.2	13.3	3.1	0.0	29.1	0.0	0.0	0.1	0.5	0.6	0.0	2.5	70.5
		2022	3.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.9
		3059	2.2	0.1	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	4.3
	58	1023	37.1	9.3	1.0	5.5	12.3	4.1	7.2	2.0	204.6	0.5	0.4	6.6	290.6
		2023	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.1	0.6
		3060	8.1	4.0	2.4	0.6	5.9	0.0	0.6	1.2	0.5	0.0	0.0	1.5	24.9
	59	1024	13.3	1.4	2.3	0.8	4.7	0.0	0.1	0.0	168.9	3.9	0.1	1.6	197.1
		2024	0.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.7
		3061	2.6	0.1	0.6	0.0	3.9	0.0	0.0	0.1	0.1	0.2	0.0	0.5	8.2
	60	1025	20.3	9.4	2.8	8.2	4.2	0.0	0.0	0.0	314.4	3.0	0.2	6.3	368.9
		2025	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.3	2.7
		3062	2.8	1.1	7.3	0.2	2.9	0.0	0.0	0.0	40.1	4.3	0.0	1.6	60.4
Transect 8	161	1036	10.5	6.1	0.1	8.2	30.9	33.7	0.0	0.0	59.5	0.4	0.3	3.4	153.0
		2036	0.3	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1.0
		3078	17.2	4.9	0.1	3.2	15.2	58.9	0.0	0.1	8.8	0.3	0.0	2.5	111.2
	162	1037	46.2	17.0	8.4	2.2	8.9	0.5	7.3	1.4	12.8	0.2	0.0	1.3	106.2
		2037	3.4	5.8	0.0	0.1	0.0	0.1	0.0	0.0	0.4	0.0	0.0	0.3	10.0
		3079	13.4	0.4	3.9	0.1	11.4	0.0	0.0	0.4	0.5	0.1	0.2	1.4	31.9
	163	1038	27.2	3.4	1.0	1.3	16.5	0.2	3.9	2.3	162.2	0.0	0.0	0.4	218.5
		2038	3.6	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
		3080	66.2	9.6	1.3	0.8	12.4	0.0	0.0	3.7	0.3	0.6	0.0	0.1	95.0
	164	1039	18.8	2.4	1.0	3.9	3.6	0.0	0.0	0.0	119.8	2.0	0.8	0.9	153.1
		2039	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	3.3
		3081	76.2	6.4	25.1	1.1	2.4	0.0	0.0	3.1	2.4	1.1	0.3	0.4	118.5
		3082	18.6	0.6	10.0	1.1	1.6	0.0	0.0	1.3	71.0	1.6	0.5	1.3	107.7
	165	1040	5.1	1.7	1.2	1.4	1.9	0.0	0.7	0.0	49.0	5.3	0.2	0.3	66.9
		2040	1.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.5	0.2	0.0	6.4
		3083	13.0	5.4	0.5	2.0	0.0	0.0	0.0	0.0	113.4	13.4	1.2	0.0	148.9
	261	1041	4.9	7.3	1.1	10.6	0.0	54.2	0.6	0.0	14.6	0.0	2.1	10.7	106.1
		2049	0.1	0.1	0.0	0.5	0.0	4.9	0.0	0.0	0.9	0.0	0.0	0.0	6.4
	262	1042	13.5	3.1	2.7	14.4	11.4	7.4	2.7	1.0	40.2	0.6	0.5	1.3	98.8

APPENDIX 5. Continued

	Stat.	Samp	Hydr	Cteno	Ptero	Chaet	Fish	Mysid	Eupha	Dec	Copep	Hyper	Gamm	Other	Total
Transect 8	262	2050	0.6	4.6	0.1	0.1	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.2	7.3
		3092	7.2	0.3	12.3	0.6	4.8	0.0	0.0	0.0	0.5	0.0	0.0	1.9	27.6
		3093	2.3	0.0	8.3	0.4	2.2	0.0	4.3	0.0	28.8	0.0	0.0	0.9	47.1
		3094	13.6	0.1	7.5	3.7	11.9	5.1	12.6	2.0	92.7	0.2	0.0	3.0	152.5
		3095	25.7	1.1	4.4	19.9	12.9	14.7	8.7	2.4	61.1	2.8	2.7	4.9	161.4
	263	1043	13.7	8.1	0.4	1.5	2.6	0.7	2.4	1.1	129.3	1.3	0.3	2.3	163.6
		2051	0.1	1.1	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.1	3.3
		3096	4.7	7.2	0.8	0.2	1.7	0.0	0.0	0.0	3.8	0.0	0.0	0.0	18.3
		3097	36.4	0.7	4.8	0.1	7.8	0.0	0.0	0.3	0.1	0.3	0.4	0.1	50.9
		3098	17.0	2.3	0.3	1.4	11.0	0.0	1.1	0.2	55.5	0.8	0.8	3.0	93.3
	264	1044	21.3	4.7	1.4	4.8	9.2	0.0	0.4	0.7	112.4	1.7	0.3	2.0	158.9
		2052	1.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	2.4
		3099	0.1	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.3	4.3
		3100	8.9	2.1	3.4	0.1	1.0	0.0	0.0	0.4	0.2	2.5	1.0	1.6	21.4
		3101	4.3	22.5	0.9	0.8	7.3	0.0	0.0	0.0	0.2	0.8	0.8	2.7	40.2
	265	1045	18.1	2.5	1.9	8.9	0.4	0.0	0.0	0.0	261.1	3.4	0.2	1.7	298.2
		1046	9.3	5.9	6.4	0.8	2.5	0.0	0.0	0.0	71.6	5.6	0.0	0.4	102.5
		2053	9.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	9.7
		3102	0.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.4	1.2
		3103	6.5	2.8	29.8	0.0	5.8	0.0	0.0	0.0	0.4	1.7	0.3	2.1	49.6
		3104	18.6	3.7	2.1	0.1	1.6	0.0	0.0	0.0	4.8	3.0	0.7	0.8	35.5
Transect 9	66	1026	3.9	1.2	0.0	1.4	13.2	13.2	0.7	0.2	25.4	0.1	0.1	0.6	59.9
		2026	0.1	0.0	0.0	0.1	0.8	0.4	3.8	0.0	4.2	0.0	0.0	0.0	9.4
		3063	16.9	8.3	0.0	1.6	43.4	45.6	0.3	0.2	55.6	0.0	0.0	2.1	174.0
	67	1027	6.9	9.2	0.5	10.1	31.1	21.3	13.5	1.1	42.2	0.6	2.6	2.7	141.9
		2027	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.8
		3064	4.1	3.0	0.7	2.4	5.5	3.8	5.9	0.6	22.2	0.2	0.0	0.9	49.3
	68	1028	31.9	1.7	0.9	6.0	25.5	2.4	4.8	0.4	102.7	1.2	0.1	1.2	178.8
		2028	0.3	1.0	0.6	0.0	4.4	0.0	0.0	0.0	0.1	1.3	0.0	0.0	7.5
		3065	52.5	3.9	0.2	2.7	9.1	0.2	0.0	0.3	8.2	1.8	2.1	0.9	82.0
	69	1029	7.6	0.7	5.1	2.3	0.6	0.0	0.0	0.0	81.5	1.4	0.7	1.7	101.5
		2029	1.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	2.0
		3066	7.9	1.9	18.8	0.0	11.0	0.0	0.0	0.0	0.6	1.3	0.2	0.9	42.6
	70	1030	11.3	1.1	1.3	3.8	3.0	0.0	0.0	0.0	111.6	1.3	0.5	0.2	134.3
		2030	0.2	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.4
		3067	8.7	1.1	4.3	0.5	0.0	0.0	0.0	0.0	25.0	0.1	0.9	1.3	41.8
Transect 11	76	1031	24.7	14.8	0.1	45.8	36.2	24.5	0.0	0.0	70.9	0.7	0.2	5.9	223.7
		2031	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	77	1032	20.8	35.3	2.2	74.9	36.6	1.9	0.0	0.6	50.1	0.3	0.2	7.7	230.6
		2032	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	2.3
		3068	1.0	3.0	0.0	8.5	0.0	0.8	0.0	0.0	4.4	0.0	0.4	3.7	21.9
		3069	57.3	30.6	0.3	9.7	9.7	0.1	0.3	0.7	9.3	0.5	1.1	11.4	131.0
	78	1033	14.7	29.5	4.6	12.4	8.3	2.9	0.0	0.3	98.3	2.0	0.1	6.9	179.9
		2033	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.5	0.0	1.0
		3070	45.5	16.0	7.7	3.0	9.1	0.0	0.0	2.4	16.7	0.6	0.6	12.7	114.4
	79	1034	9.3	9.8	13.2	11.6	9.1	1.5	0.0	0.6	459.3	3.7	0.6	7.9	526.6
		2034	0.2	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	2.1

APPENDIX 5. Continued

	Stat.	Samp	Hydr	Cteno	Ptero	Chaet	Fish	Mysid	Eupha	Dec	Copep	Hyper	Gamm	Other	Total
Transect 11	79	3071	1.1	0.0	2.7	0.0	5.7	0.0	0.0	0.0	0.7	0.0	0.0	2.8	13.1
		3072	3.9	5.2	53.4	0.3	16.4	0.0	0.0	0.0	0.9	0.1	0.0	1.7	81.9
		3073	17.7	40.7	7.9	1.4	10.2	0.0	0.0	1.1	177.5	6.9	0.9	9.2	273.4
	79.3	1035	5.4	0.9	3.4	0.4	5.9	0.0	0.0	0.4	95.4	1.7	0.2	2.1	115.7
		2035	3.7	2.1	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.3	1.7	11.6
		3074	0.5	0.1	12.1	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	2.1	17.0
		3075	6.0	31.1	4.3	0.0	7.2	0.0	0.0	0.0	0.3	1.2	0.2	2.5	52.7
		3076	8.4	3.6	0.6	0.6	8.2	0.0	0.0	0.5	52.1	2.8	0.1	0.3	77.2
		3077	12.1	1.1	1.3	1.0	5.5	0.0	0.0	0.7	66.0	2.7	1.2	1.7	93.2
Transect 17	201	2041	0.5	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.9	0.1	0.1	0.2	1.9
		2042	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.9
		3084	65.1	0.2	0.0	0.3	13.5	35.0	0.8	0.2	15.5	3.3	0.0	0.8	134.9
		3085	21.8	0.6	0.0	0.0	0.0	2.8	0.2	0.0	2.2	0.0	0.0	0.3	27.9
	202	2043	1.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	1.9
		2044	1.2	2.2	0.0	0.1	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.3	5.1
		2045	0.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.1	1.7
		2046	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.3
		3086	27.9	0.9	0.0	0.0	1.1	1.8	0.0	0.0	1.7	0.5	0.0	1.9	35.9
		3087	30.7	1.4	0.0	0.6	64.2	138.7	4.1	0.5	31.0	1.2	0.1	8.3	280.9
		3088	37.9	3.9	0.0	0.5	18.2	125.5	0.0	0.3	21.3	1.7	0.3	2.9	212.5
		3089	23.0	2.2	0.0	1.0	43.7	55.1	3.8	1.2	19.3	7.9	0.0	1.1	158.4
	203	2047	1.0	9.0	0.0	0.0	0.0	0.1	0.0	0.0	1.0	0.0	0.0	0.0	11.1
		2048	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
		3090	12.9	0.1	0.3	1.8	5.5	25.9	0.8	1.2	34.6	10.2	0.2	1.2	94.7
		3091	4.8	0.9	0.2	2.3	9.1	17.1	1.8	1.2	44.9	2.1	0.0	2.2	86.4

ZOOPLANKTON OF A BOWHEAD WHALE FEEDING AREA OFF THE YUKON COAST IN AUGUST 1985

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November 1986

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ACKNOWLEDGEMENTS

This study was conducted for Indian and Northern Affairs Canada. We thank Dr. D. Stone and R. Hurst for their support of this project.

Field studies were conducted from the MV 'Sequel' during the last half of August 1985. We owe a special debt of gratitude to D. MacWatt, owner of the MV 'Sequel', and to skipper W. Bellham for their help during field studies. We also thank G.D. Hobson, Polar Continental Shelf Project, Energy Mines and Resources, for accommodation in Tuktoyaktuk; and M. Lawrence, Department of Fisheries and Oceans, and B. Mackie, Beaufort Environmental Support Services, for help in outfitting the MV 'Sequel' and other favours.

The studies reported herein were carried out by the authors and by R. Buchanan and L. Martin of LGL Ltd. and J. Marko and R. Birch of Arctic Sciences Ltd. G.A. Borstad Associates Ltd. provided field information about the locations of suspected surface water anomalies. Satellite imagery data were provided by W. Gould, Environmental Data Information Service, Capital Heights, Maryland, and by W. Emery and P. Nowlan, Remote Sensing Centre, University of British Columbia, Vancouver.

We would like to thank M. Brunato, M. Fabijan, D. Lewis and N. Stallard of LGL for processing the zooplankton samples in the laboratory. J. Barrie of LGL and M. Jones of the Water Analysis Lab, Memorial University, St. John's, Newfoundland, conducted calorimetric determinations of the zooplankton. Dr. Allen Place, Department of Biology, University of Pennsylvania, Philadelphia, analyzed the lipid content of zooplankton and whale faeces. Whale faeces were provided by K.J. Finley and C.R. Evans of LGL Ltd.

This study benefited from the expertise of W. Griffiths, W.J. Richardson and D. Thomson, who conducted a complementary study of zooplankton and bowhead whales in the Alaskan Beaufort Sea during September 1985. These individuals provided significant input to the design and analysis of the results reported herein. R.A. Davis directed the project and we thank him and W.J. Richardson for their comments on a draft of this report. N. Andrews, C. R. Evans, M. Fabijan, C. Holdsworth, P.L. McLaren, S. Norton, S. Cutcliffe, B. Griffen and R. Stark helped in the preparation of this report.

INTRODUCTION

Bowhead whales, Balaena mysticetus, winter in the Bering Sea and annually migrate to summering areas in the Chukchi Sea, Beaufort Sea and Amundsen Gulf (Fraker and Bockstoce 1980). It has been assumed that bowheads, like other mysticete whales, primarily feed during the summer; if so, then annual migrations are probably undertaken to reach preferred feeding areas. This would imply that summering areas are rich in food, and important to the whales that travel a round-trip distance of several thousand kilometres to feed in those areas.

Bowhead whales generally arrive in Canadian waters in June. At that time they are present in the extreme eastern Beaufort Sea and Amundsen Gulf area, having travelled from Point Barrow, Alaska, to Banks Island through offshore ice cracks. By mid to late August, bowheads are present inshore along the Mackenzie Delta and Yukon coastlines, and they remain in those areas until September. By early to mid September, some bowheads begin to move westward toward and into the Alaskan Beaufort Sea, but other individuals remain in the Canadian Beaufort Sea until late September or early October.

There are no data on the types or quantities of food consumed by bowheads that summer in the Canadian Beaufort Sea and Amundsen Gulf. During fall migration past Kaktovik, Alaska (120 km west of the Yukon/Alaska border), bowhead whales are hunted by native people; food samples have been obtained from the stomachs of the harvested animals. Lowry and Frost (1984) reported the diets of eight bowheads taken at Kaktovik during the autumns of 1979-82 as 66% copepods, 31% euphausiids and minor amounts of mysids, hyperiid and gammarid amphipods, other invertebrates and fish (percentages determined from total sample volumes). Lowry and Frost concluded that during the fall, bowhead feeding is primarily directed at organisms in the water column. This is apparently also true earlier in the summer, when the whales are in the Canadian Beaufort Sea. Würsig et al. (1985) described three modes of apparent feeding behaviour: skim feeding at the surface, feeding near the bottom, and feeding in the water column. Würsig et al. (1985) suspected that some whales fed in the water column in each year from 1980-82. In 1982, other types of feeding behaviour (surface feeding, feeding at or near the bottom) were rare.

There is considerable concern that industrial activities associated with hydrocarbon development in the Canadian Beaufort Sea may result in adverse environmental impacts to bowhead whales (LGL et al. 1984; ESL et al. 1985; Richardson et al. 1986a). Bowheads, for example, have been known to occur in large numbers in areas where industrial activity is in progress. Industrial activity in parts of the Canadian Beaufort Sea deep enough to be occupied by bowheads began in 1976. Bowheads were numerous in the zone of industrial activity in three of five years from 1976-80, but they were not commonly observed in the industrial zone in any of three years from 1982-84 (Richardson et al. 1985) or in 1985 (Norton and Harwood 1986). One hypothesis that has been developed to account for this change in distribution is that noise and disturbance are now excluding bowheads from the area of industrial activity (ESL et al. 1985).

Richardson et al. (1985) noted, however, that there also was much year-to-year variation in the distribution of whales outside the industrial zone during the 1980-84 period. They also noted that assumed variation in food availability (i.e., locations where zooplankton is sufficiently concentrated to be economic for the whales to exploit) may also account for the observed variability in bowhead distribution since industrial activity began. Such concentrations of food are probably controlled by oceanographic and meteorological factors that are independent of industrial activity. Thus, a second hypothesis which may explain the change in whale distribution is that the bowheads are simply following an annually varying food supply.

This study was designed to address the question of whether variation in food availability may account for the observed year-to-year variability in bowhead distribution. Due to logistic constraints, it was not possible to sample zooplankton both along the Yukon coast and in the area of industrial activity. Nevertheless, it was thought that sampling in an area where bowheads were present in 1985 would provide some useful information. Large numbers of bowheads were present off the Yukon coast during the late summers of 1983 and 1984, so this area was chosen as the 1985 study site. The results obtained could then be compared with a zooplankton and bowhead study conducted in 1980-81 near Richards Island, in the area of industrial activity (Griffiths and Buchanan 1982), and with the results of a September 1985 study of zooplankton and bowheads in the eastern Alaskan Beaufort Sea (Richardson [ed.] 1986).

There have been no extensive systematic studies documenting the biomass of zooplankton in the Canadian Beaufort Sea, or of the factors affecting that biomass. However, a number of recent studies have provided indirect evidence that oceanographic features may be important in determining zooplankton abundance in the Beaufort Sea. In turn, high zooplankton densities are believed to be important to feeding bowhead whales (Griffiths and Buchanan 1982). This indirect evidence was summarized in the 1984-1985 report of the Beaufort Environmental Monitoring Project (ESL et al. 1985) and in Thomson et al. (1986). Borstad (1985) and Harwood and Borstad (1985) reported that the Herschel/Yukon coast and Cape Bathurst areas, where large numbers of bowheads often occur, commonly exhibit surface oceanographic features indicative of high levels of turbulence or upwelling activity. Several instances of coincidence of bowhead whales with thermal fronts, shear zones or surface convergences, as indicated by ice strings, were documented in the two studies. While no in situ zooplankton data were acquired during these studies, zooplankton are commonly aggregated at these types of physical features elsewhere (Denman and Powell 1984). These findings suggest that the local aggregation of zooplankton by physical mechanisms may be important for feeding bowhead whales.

The outflow of fresh, turbid water from the Mackenzie River into the southeastern Beaufort Sea results in a 'plume' of freshened silt-laden water overlying the denser marine water. Thomson et al. (1986) mapped the highly variable wind-dependent area of the Mackenzie plume using satellite imagery and inferred prevailing winds for the period 1980-1983. The observed distributions of bowhead whales were then compared with the distributions of the plume. These comparisons indicated that the presence of whales in the area north of Richards Island may be associated with wind-driven contraction of the areal extent of the low salinity plume. There was some evidence that whales tended to occur near or just beyond the plume edge. Zooplankton biomass is lower within the low salinity plume than in the more saline marine waters (Griffiths and Buchanan 1982). However, whales sometimes were absent at times and locations where wind and physical oceanographic conditions suggested that food may have been available. This was particularly true in 1982 and 1983.

Studies in other areas have shown that the mechanisms causing zooplankton concentrations may include complex physical and biological interactions that are difficult to resolve. Primary productivity can be enhanced through upwelling of nutrient rich waters, causing an increased food supply for zooplankton. Zooplankton can also be concentrated through convergent surface flow patterns or along density gradients. Convergence and concentration of zooplankton often occur in association with fronts and eddies (Bowman and Esais 1978; Parsons and Takahashi 1973). Such features occur over spatial scales ranging from tens of metres to several kilometres, usually associated with areas where differing water masses abut. In the Canadian Beaufort Sea, strong, large-scale gradients are commonly found along the boundary of the warm, fresh and turbid Mackenzie River plume off the Mackenzie Delta. Other processes of potential importance in producing convergence zones within the surface layer include (1) internal waves occurring along horizontal density interfaces, and (2) wind-induced Langmuir circulation cells, occurring as vertically-oriented vortices within the surface layer. Because features of this type normally occur on small spatial scales (tens to hundreds of metres), they cannot be resolved using satellite imagery.

Study Area

We investigated oceanographic conditions and zooplankton in a study area offshore from the Yukon coast between Shingle Point and Herschel Island (Fig. 1). Within the study area, we established transects oriented in a northeasterly direction from, or generally perpendicular to, the coastline. Along each transect, oceanographic and plankton sampling stations were established at the 5 m and 10 m depth contours, and at distances 5, 10 and 15 n.mi. seaward of the 10 m station. Incidental sampling was conducted elsewhere as conditions warranted.

During the summer months, the large-scale distribution of surface water properties in the southeastern Beaufort Sea can be divided into three broad categories (Harper and Penland 1982; Fissel and Birch 1984; Borstad 1985; Thomson et al. 1986).

Intense River Plume Water.--This is an area in which the surface layer has high temperatures and turbidities, and low salinities; in the study area, it is found adjacent to the Mackenzie River Delta. The best characterization of the offshore boundary of the intense plume is through a strong horizontal gradient (or front) in which the temperature and turbidity decrease considerably over distances of a few kilometres or less. The intense plume extends typically to depths of 3 to 5 m, or to the bottom in the very shallow deltaic areas.

The values of temperature and turbidity within the intense plume vary according to the characteristics of the Mackenzie River discharge. The drainage pattern of the Mackenzie Delta is illustrated in Figure 2, and the

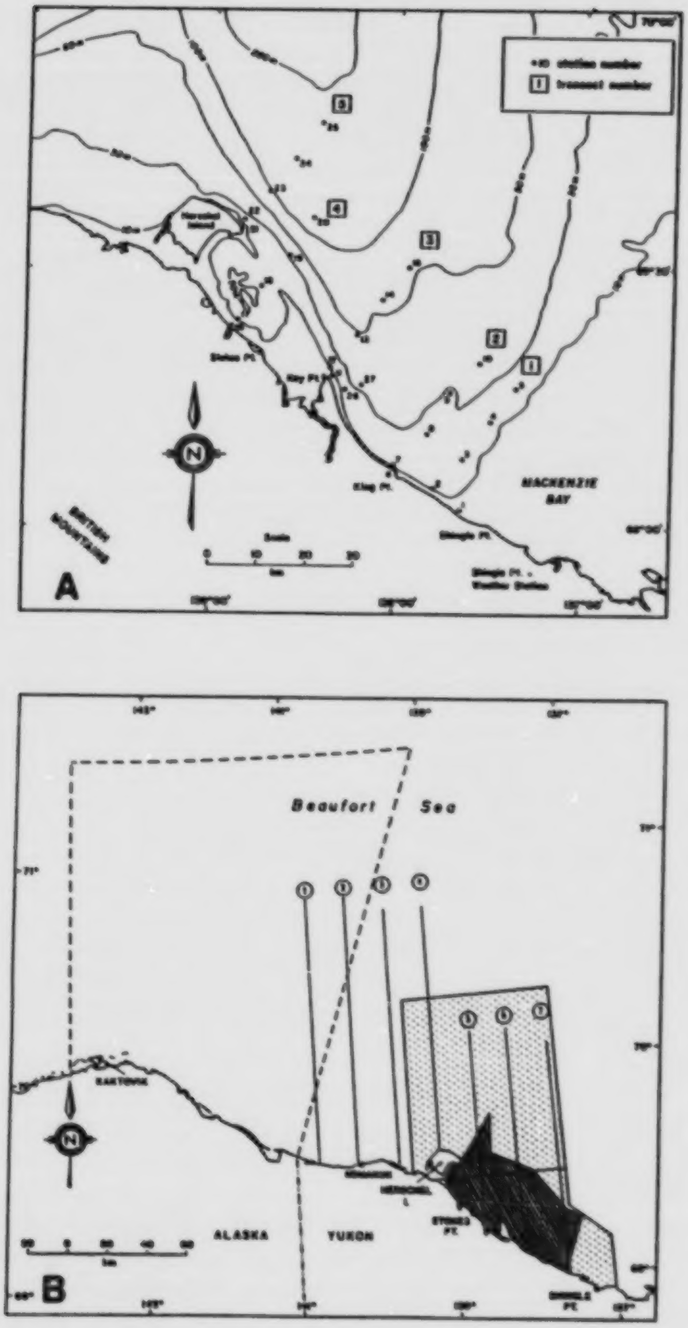
station number
transect number
5
4
3
2
1
Herschel Island
Kay Pt.
King Pt.
MACKENZIE BAY
BRITISH MOUNTAINS
Scale
0
10
20
30
km
Shingle Pt.
A
Beaufort Sea
KAKTOVIK
HERSCHEL I.
STOKES PT.
ALASKA
YUKON
SHINGLE PT.
B

Figure 1. (A) Map of the study area showing the locations of sampling stations and transects. (B) The study area (hatched) in relation to other 1986 bowhead studies conducted nearby (bowhead feeding, Richardson [ed.] 1986-enclosed by dashed line; photogrammetry, Davis et. al. 1986-dotted area; ESL/ESRF aerial surveys, Norton and Harwood 1986-transect lines). Only portions of the study areas of Davis et. al. (1986) and Norton and Harwood (1986) are indicated.

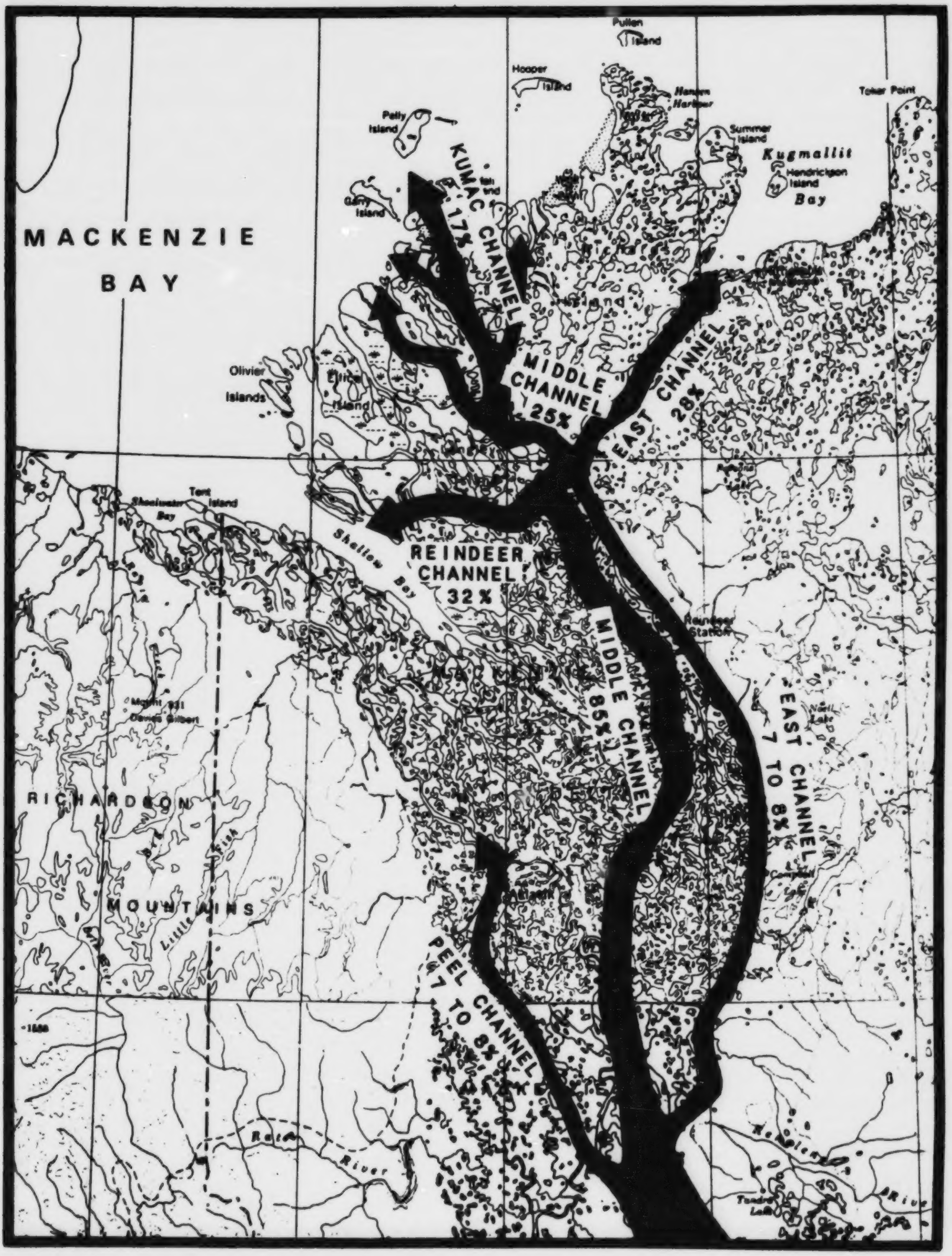
Pullen Island
Hooper Island
Pelly Island
Hansen Harbour
Toker Point
Summer Island
Kugmallit Bay
Hendrickson Island
Garry Island
KUMAC CHANNEL 17%
MACKENZIE BAY
MIDDLE CHANNEL 25%
EAST CHANNEL 28%
Olivier Islands
Ellice Island
Tent Island
Shoalwater Bay
Shallow Bay
REINDEER CHANNEL 32%
Reindeer Station
MIDDLE CHANNEL 85%
EAST CHANNEL 7 TO 8%
RICHARDSON MOUNTAINS
PEEL CHANNEL 7 TO 8%
Rat River
Tundra Lake

Figure 2. Generalized distribution of Mackenzie River outflow through channels of the Mackenzie Delta (from Fraker et al. 1979).

seasonal cycles of river volume discharges and water temperatures are provided in Figures 3 and 4. Peak values of temperature and turbidity within the intense plume normally occur in late July, at levels of 12-16°C and 100-200 ppm (equivalent to secchi depths of less than 1 m). By late August-early September, temperatures can decrease to 6-10°C with a corresponding change in turbidity levels.

Diffuse Plume Water.--The influence of Mackenzie River water extends over a larger surface area beyond the intense plume. Within this larger area, referred to as the diffuse plume, temperature and turbidity levels within the surface layer are moderately greater than in the cold, clear surface waters of the Arctic Ocean. The diffuse plume is not as homogeneous as the intense plume. Variations in water properties occur as local minima or maxima. Filaments and meanders protrude outward from the front marking the outer edge of the intense plume. Due to the variability within the zone and the lower values of temperature and turbidity, it is often difficult to map the outer boundary of the diffuse plume unambiguously. The diffuse plume occurs as a thin surface layer, extending to depths ranging from 2 to 10 m. Cold, clear arctic water is found beneath the diffuse plume.

Arctic Ocean Water.--The remainder of the area has the cold and clear characteristics of Arctic Ocean water. Due to the preponderance of sea-ice within the area, surface temperatures are usually less than 1-2°C. (In years of extensive early clearing of sea-ice offshore, solarheating can cause warming of surface temperatures up to 4-5°C.) The absence of particulate matter results in extremely low turbidity levels, typically equivalent to secchi depths of 10 m or more.

Areal Extent of Surface Water Types.--The typical and maximal spatial extent of the intense and diffuse plumes have been mapped using four years (1980-1983) of satellite imagery (Fig. 5, from Thomson et al. 1986). In that study, the region-wide surface wind patterns were identified as the key element influencing the location of the plume. Under westerly or northwesterly winds, the plume is driven eastwards and inshore along the delta coastline and the Tuktoyaktuk Peninsula to Liverpool Bay. The westward extent of the river-influenced water is limited to an area between 137°W and 138°W under westerly wind regimes.

With easterly winds, the intense and diffuse plumes are displaced westward (Fig. 5). Typically, the western edge of the intense plume remains east of 138°W, although it has been observed (on one occasion: 14 August 1983) as far west as 140°W, which is beyond Herschel Island. In most instances, the diffuse plume can be detected westward well beyond Herschel Canyon. Under prolonged easterly winds, it may extend as far west as the Alaskan border, and sometimes beyond (Fissel et al. 1986). With easterly winds, the diffuse plume occurs as either (1) a broad band bordering the Yukon coastline or (2) an offshore plume oriented northwestward, separated from the Yukon coastline by the presence of a nearshore band of cold, clear Arctic Ocean water.

Objectives

The broad objective of this study was to conduct field investigations on oceanographic conditions and the presence of planktonic food in order to better understand the significance of the study area in the bowhead whales'

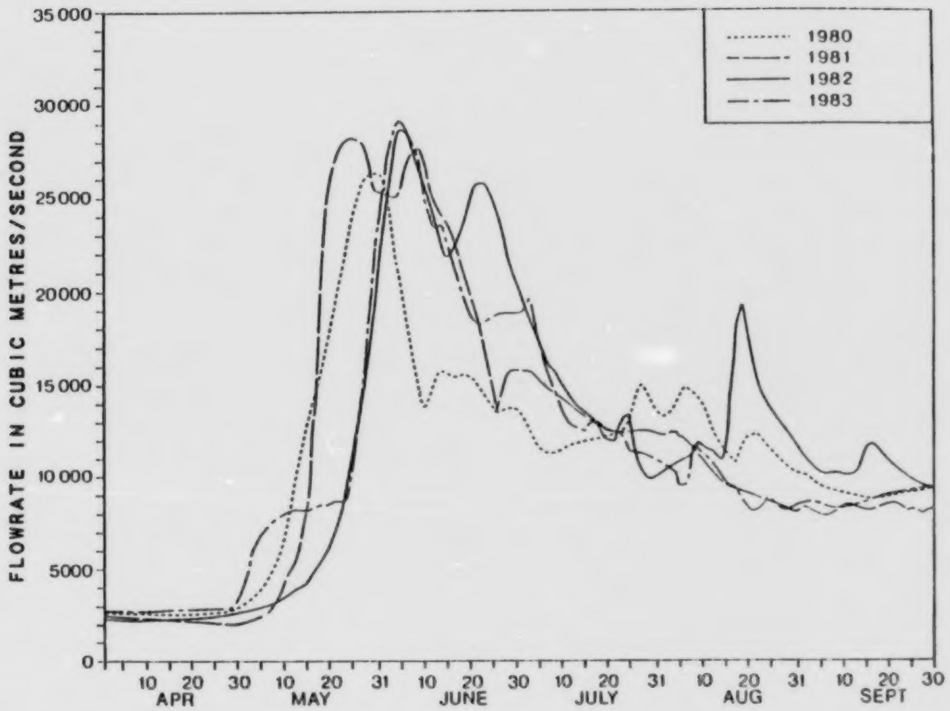

Figure 3. The volume discharge of the Mackenzie River, 1980-1983, for the months April to September. The data were from the permanent gauging station on the Mackenzie River located above the junction with the Arctic Red River, operated by the Inland Waters Branch, Environment Canada (from Thomson et al. 1986).

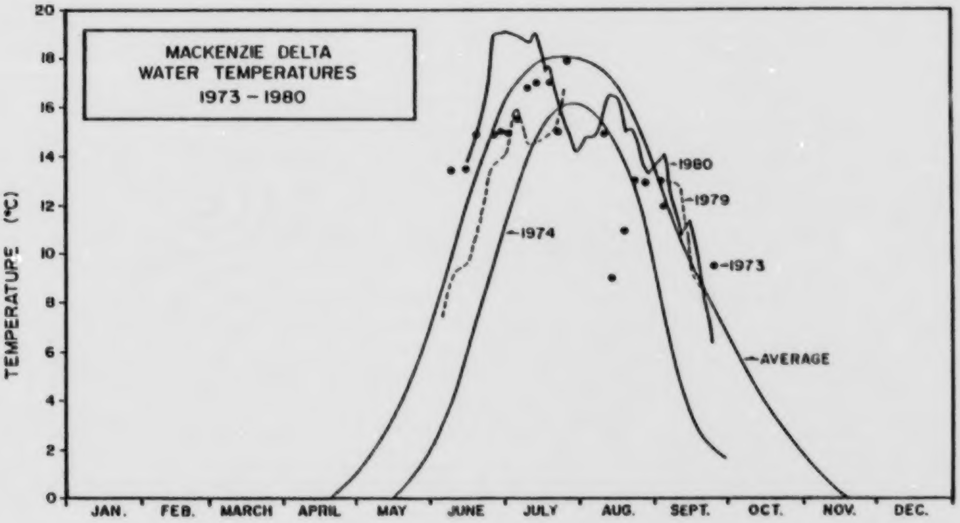

Figure 4. Water temperature measurement data for the Mackenzie River near Arctic Red River (Davies 1975; B.C. Hydro unpubl. data) and at points in the Mackenzie Delta (from Marko et al. 1983).

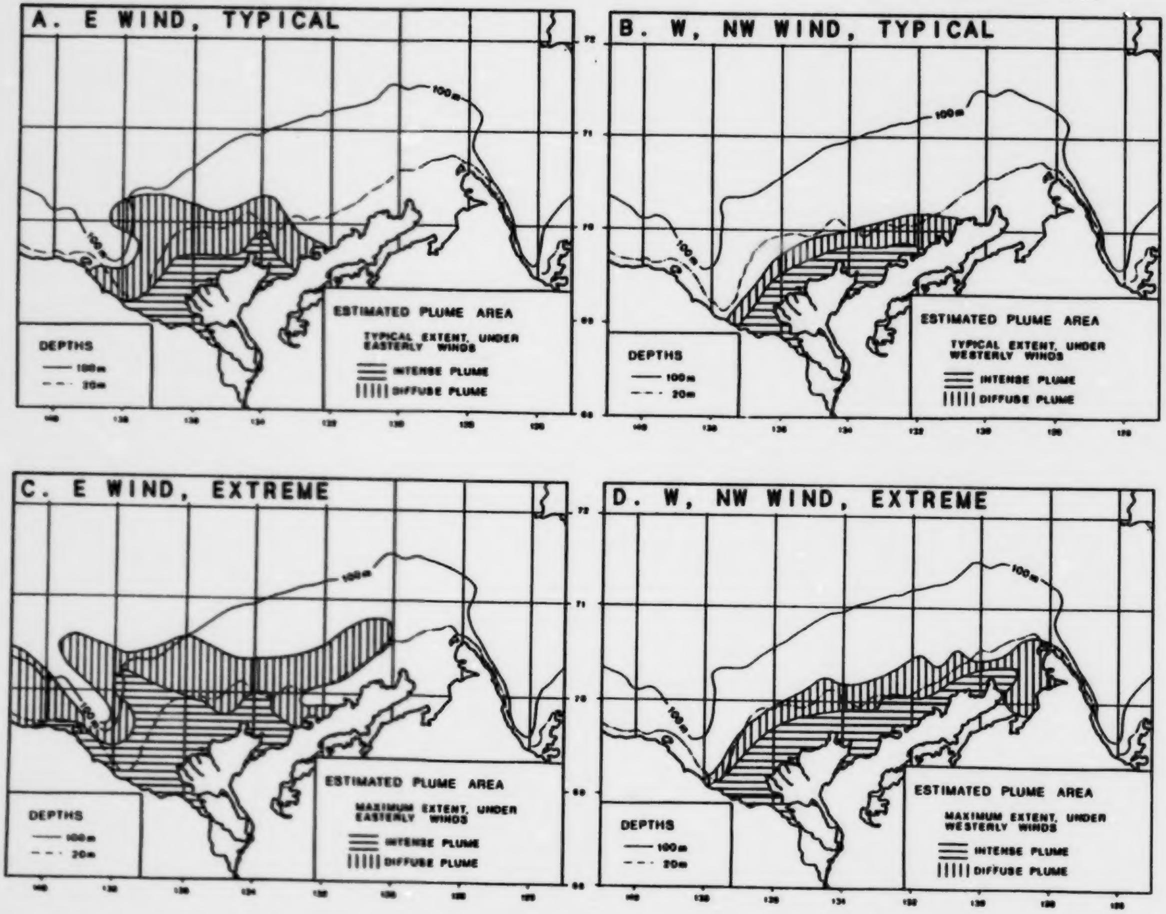
A. E WIND, TYPICAL
100m
ESTIMATED PLUME AREA
TYPICAL EXTENT, UNDER EASTERLY WINDS
INTENSE PLUME
DIFFUSE PLUME
DEPTHS
100m
20m
B. W, NW WIND, TYPICAL
ESTIMATED PLUME AREA
TYPICAL EXTENT, UNDER WESTERLY WINDS
INTENSE PLUME
DIFFUSE PLUME
DEPTHS
100m
20m
C. E WIND, EXTREME
ESTIMATED PLUME AREA
MAXIMUM EXTENT, UNDER EASTERLY WINDS
INTENSE PLUME
DIFFUSE PLUME
DEPTHS
100m
20m
D. W, NW WIND, EXTREME
ESTIMATED PLUME AREA
MAXIMUM EXTENT, UNDER WESTERLY WINDS
INTENSE PLUME
DIFFUSE PLUME
DEPTHS
100m
20m
72
71
70
69
68

Figure 5. The extent of the Mackenzie River plume, as derived from 1980 to 1983 satellite imagery data, under the dominant easterly and west-northwesterly wind conditions. (a) and (b) are estimated typical conditions, while (c) and (d) illustrate the estimated maximum extent of the plume (from Thomson et al. 1986).

annual energy budget. The following tasks were undertaken to meet this objective:

Task 1: Physical Oceanographic Characterization of the Study Area.--Physical data were collected to provide information on the oceanographic processes described above, and to assist in interpreting simultaneous observations of zooplankton and bowhead whales. Satellite remote-sensing techniques were used to determine the synoptic distributions of surface oceanographic features throughout the study area. Horizontal and vertical profiles of temperature and salinity were acquired by boat-based sampling along oceanographic transects in order to examine subsurface oceanographic features and to provide calibration data for the satellite imagery. From the boat- and satellite-based data sources, large-scale oceanographic features were identified, and the observed time-dependent changes were interpreted in relation to the local wind fields. The concurrent measurements of zooplankton abundances and physical oceanographic data were designed to permit testing of the hypothesis that zooplankton aggregations tend to occur in or near fronts, eddies and areas of upwelling.

Task 2: Determination of Zooplankton Biomasses in the Study Area.--Zooplankton are patchily distributed in the ocean; hence, we used a variety of methods to estimate zooplankton biomass and abundance. Oblique tows through the upper portions of the water column were conducted to describe zooplankton communities in the study area. Horizontal tows were conducted to sample apparent 'patches' of zooplankton as identified by echosounding (hydroacoustic) techniques. We sampled zooplankton in the vicinity of feeding whales for comparison with results obtained in areas with no bowheads. We tested whether amounts of zooplankton were correlated with ordinal estimates of echo-density from the hydroacoustic tapes; and finding that this was so, we were able to estimate zooplankton abundance in areas not sampled with traditional plankton sampling methods. Drop-nets were used to estimate the abundances of organisms at or near the bottom. Lengths of numerous zooplankters were measured.

Task 3: Assessment of the Food Value of Zooplankton Available to Bowheads.--Calorimetric determinations were made on most of the zooplankton samples collected with oblique and horizontal tows. In addition, determinations were made on several taxa of potential bowhead food. Lipid composition and amount were also determined for several samples.

Task 4: Integration.--Results obtained from the above tasks were compared with those collected during September 1985 in a similar but more extensive study of bowhead food availability off the Alaskan coast between the Yukon/Alaska border and Kaktovik (Richardson [ed.] 1986). Results were also compared with previous zooplankton sampling in the Canadian Beaufort Sea conducted by Griffiths and Buchanan (1982). Simultaneous studies of the distribution of bowhead whales in the study area (Norton and Harwood 1986) and the sizes of those whales as determined from photogrammetry (Cubbage and Calambokidis 1986; Davis et al. 1986), provided further information about bowhead whales in the study area.

MATERIALS AND METHODS

Regional Sea-ice Patterns and Wind Conditions

Information on sea-ice patterns during the course of the study was obtained from the weekly charts of sea-ice conditions prepared by Ice Central, Atmospheric Environment Service, Environment Canada.

Wind data within the study area were obtained at three locations along the Yukon coastline:

- Shingle Point Weather Station operated by the DEW-line contractor for the Atmospheric Environment Service, Environment Canada. For this study, hourly measurements of wind speed and direction, air temperature, and sea-level pressure were obtained.
- Various marine vessels operating off the southeast coast of Herschel Island. The data, at 6-hourly measurement intervals, were obtained through the Beaufort Weather Office, Atmospheric Environment Service, Environment Canada. The marine wind data were measured from sensors mounted on ship masts at varying heights above sea level. Because the heights were not available to us, no corrections have been applied to reduce the observed winds to the expected values at the standard 10 m anemometer height as used at Shingle Point.
- King Point Weather Station, operated from 26 August to 14 September 1985 as part of a coastal sediment study (Gillie 1986). The meteorological measurements were obtained with an Aanderaa weather station, and included data on wind speed and direction, and air pressure, at a sampling interval of 15 min. The weather station was operated near the beach at a ground elevation of 2 m, with the wind sensors mounted 10 m above ground level.

Satellite Data

General Description of Satellite Data Types and Sources.--Views of the overall distribution of surface water temperature and turbidity were obtained on the few clear days from images produced by the Advanced Very High Resolution (AVHRR) instruments on board the polar-orbiting NOAA-8 and NOAA-9 satellites. These images were obtained in digital computer-compatible tape (CCT) form in each of five separate bands within the overall wavelength range 0.58 µm to 12.5 µm. As transmitted by the satellite, images consist of arrays of 10-bit numbers representing the instrument's response to radiation. Each value represents the radiation from a pixel or picture element. A pixel is the minimum-resolvable portion of the earth's surface, and for a NOAA satellite is approximately 1.2 km^2 in area. Each image consists of successive scanning lines or strips aligned perpendicular to the projection of the satellite orbit onto the earth's surface. Each strip contains 2048 pixels. One image is formed for each band of wavelengths sensed by the satellite.

Ideally, the two NOAA satellites allow the observation of events on time scales as short as a few hours. Each satellite passes over the study area approximately 2-3 times per day during daylight hours, and each pass covers a wide swath (2500 km). In cloudy areas such as the Beaufort Sea, usable imagery is not obtained nearly this often. However, the availability of numerous daily overpasses greatly increases the likelihood of obtaining data from any particular portion of the area of interest during occasional periods of clear viewing.

In the present study, we used images obtained in bands 1 and 4, which correspond to visible wavelengths (0.58 μm to 0.68 μm) and 'thermal' infrared wavelengths (1.5 μm to 11.3 μm), respectively. Band 1 radiance levels (energy per unit time per unit area) are primarily associated with scattering of solar radiation from the uppermost portion of the ocean. Because band 1 reflectance is approximately proportional to the concentration of light-scattering particulates in the upper portion of the water column, band 1 AVHRR images can be used to estimate surface turbidity levels.

Radiance in band 4 and in the other 'thermal' infrared wavelength bands (3 and 5), on the other hand, is almost entirely attributable to energy radiated by the sea surface, as opposed to scattering of solar energy. As a result, the radiance in these bands is closely related to the surface temperature through the radiation laws, as implied by the 'thermal' infrared designation.

Digital images either used or considered for use in this study were obtained from three different sources:

1. Environmental Data Information Service (EDIS), U.S. Dept. of Commerce, Capitol Heights, Maryland;
2. The Arctic Weather Centre (ARWC), Atmospheric Environment Service, Edmonton, Alberta; and
3. The Remote Sensing Centre of the University of British Columbia (UBC), Vancouver, British Columbia.

Only the first of these suppliers (EDIS) was able to provide images with the full 10-bit radiance resolution as originally transmitted to ground reception stations. Other suppliers produced 8-bit versions of the transmitted images by dropping the two least significant bits in each received pixel radiance value (equivalent to integer division by 4). Although the higher resolution EDIS imagery was preferred, imagery for two viewing times, 26 August and 28 August, was available from UBC only at the lower resolution.

The six pairs of 1985 images considered in this report span the period 18-28 August (Table 1). They were selected following thorough review of the EDIS imagery collection by Mr. W. Gould of the U.S. Dept. of Commerce, and our own survey of the UBC and ARWC image collections.

Methodology for Satellite Analysis.--The digital tape images were processed using the facilities of the Image Processing Laboratory at the Institute of Ocean Sciences, Sidney, B.C., in a manner similar to that described in previous studies of bowhead whale habitats (Borstad 1985; Fissel et al. 1985, 1986; Thomson et al. 1986). The Image Processing Laboratory facilities allow the production of computer graphic representations of the

Table 1. Satellite imagery used in this study.

Satellite	Orbit	Date in August	Time (GMT)	Source*
NOAA-9	3519	18	1930	EDIS
NOAA-9	3547	20	2117	EDIS
NOAA-8	13469	21	1827	EDIS
NOAA-9	3604	24	2216	EDIS
NOAA-9	3632	26	2156	UBC
NOAA-9	3660	28	2135	UBC

* Imagery was obtained from the Environmental Data Information Service (EDIS) and from the Remote Sensing Centre of the University of British Columbia (UBC).

individual surface pixels in each distinct wavelength band. The correct position of each pixel was established on an equirectangular projection using image rectification programs and recognizable coastal landmarks. The absolute geometric accuracy is estimated to be 2 km. The results are presented on maps of two differing scales. In the large area maps, surface oceanographic features are displayed from Eastern Alaska (144°W) to the eastern limit of the Mackenzie Delta (133°W). The second map format concentrates on the study area, extending from just west of Herschel Island to the western coastline of Richards Island.

Our image processing procedure involved the combined used of the band 1 and band 4 images to identify pixels whose high radiance values in both wavelength bands indicated obstruction by cloud and/or ice. (Note: high radiance values in bands 1 and 4 correspond to high turbidities and to low temperatures, respectively). Pixels containing ice or cloud were depicted in white on the resulting colour images. Land areas were depicted in black and a latitude-longitude grid was superimposed. Pixel radiances in open-water cloud-free areas were represented as six colour-coded categories. As in earlier related studies (e.g. Thomson et al. 1986), the magnitudes and ranges of variation of the band 1 radiance in the studied areas were only about 30% of the corresponding band 4 quantities. As a result, surface spatial details were most clearly extracted from the thermal infrared data.

Calibration of Satellite Imagery Data.--An approximate in situ calibration of the satellite data, both the visible and thermal bands, was determined through comparisons with the boat-based oceanographic measurements of 23-30 August (Figs. 6 and 7). The temperature data obtained from the MV Sequel have an estimated accuracy of 0.5°C, while the secchi depths are believed to be accurate within 0.5 m. 'Best fit' regression lines were visually estimated from the boat-based calibration data (Figs. 6 and 7). Deviations from the 'best fit' regression lines are considerably larger than the above-mentioned measurement uncertainties. The large deviations most likely result from the absence of simultaneous measurements from the boat and satellite; typically the times of observation for 'paired' satellite and boat data differ by 1-2 days. In the few instances when boat- and

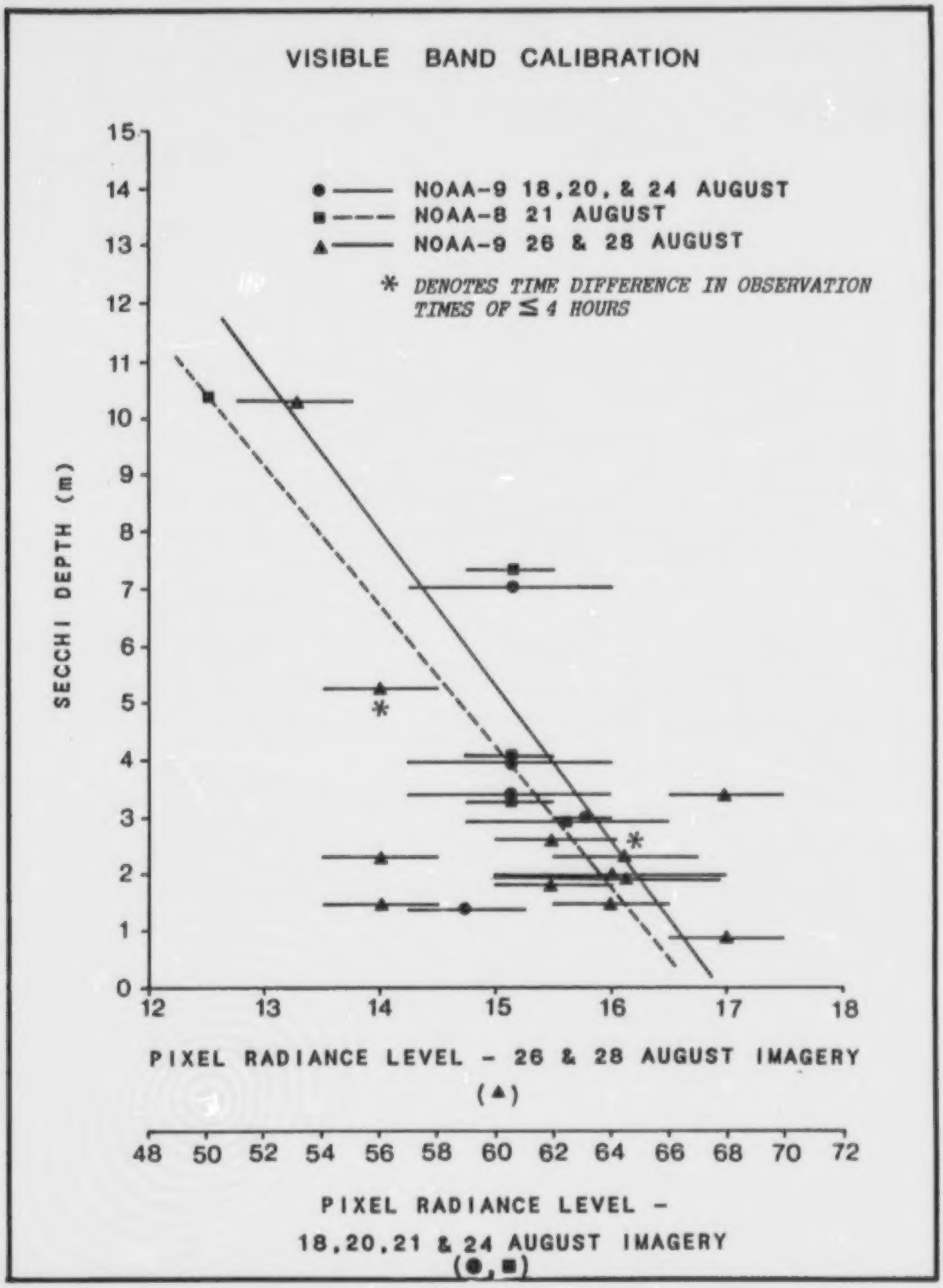

Figure 6. Comparison of AVHRR bank 1 satellite output (pixel radiance levels) with boat-based secchi depth measurements. Estimated calibration curves are presented for the NOAA-9 (solid line) and NOAA-8 (dashed line). The symbol '*' denotes those calibration data for which the observation times were within 4 hours of one another.

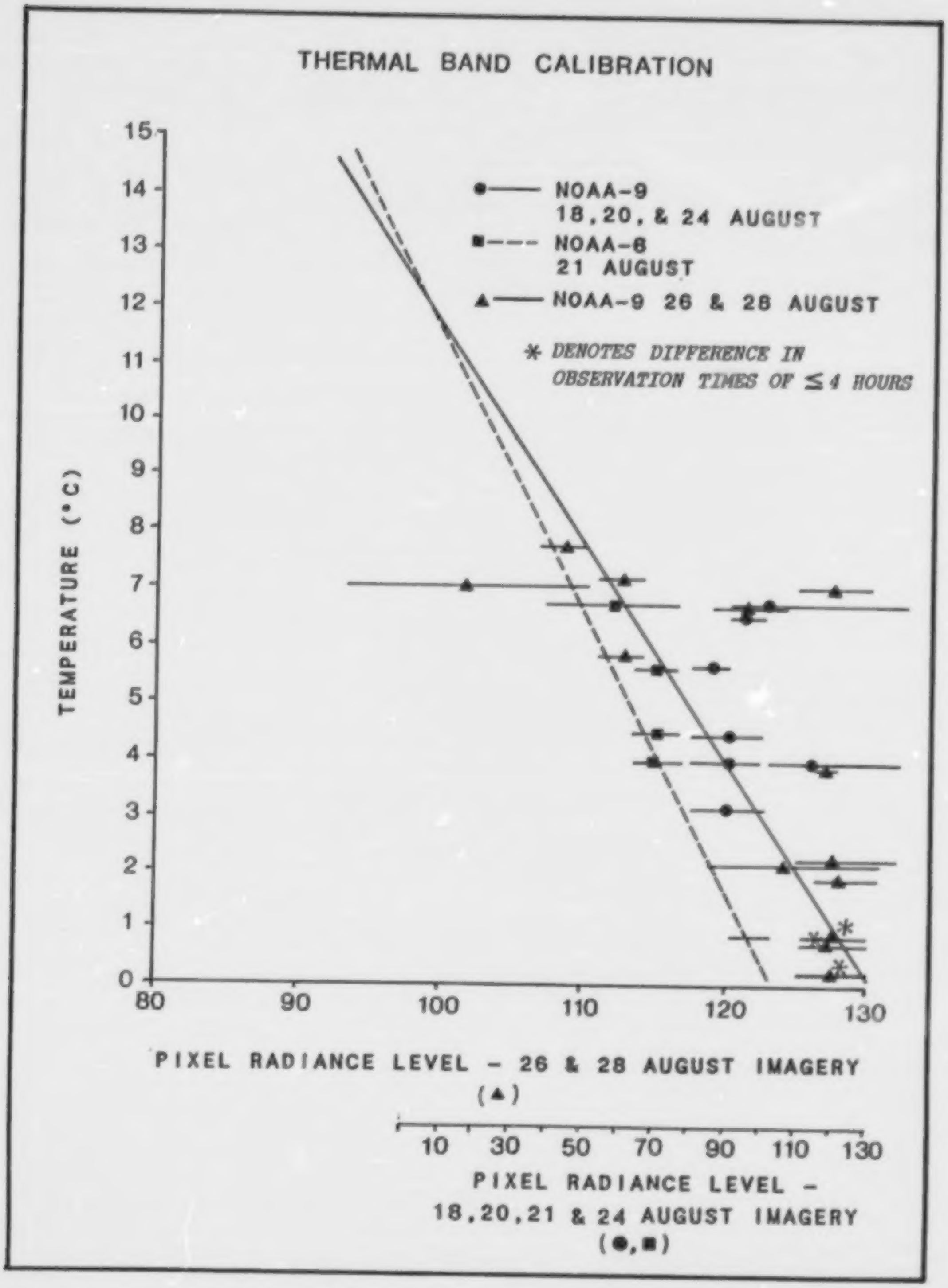

Figure 7. Comparison of AVHRR band 4 (thermal) satellite output (pixel radiance levels) with the boat-based surface temperature measurements. Presentation as in Figure 6.

satellite-based observations were collected within a few hours of one another (stations 1, 2 and 6 on 28 August as marked by * on Figs. 6 and 7), the deviations were markedly reduced. In view of the limited amount of synoptic calibration data, the imagery of 24, 26 and 28 August is considered to be representative of surface water properties to within 2°C in temperature and 2 m in secchi depth. The uncertainties of the 21 August data are further increased, since these data were obtained from a different satellite (NOAA-9) than that used to acquire all the remaining imagery (NOAA-8).

Boat-based Water Mass Data

Continuous Surface Temperature.--Surface water was pumped continuously past a (modified) Aanderaa thermistor sensor. Data from the sensor were to provide detailed surface temperatures, which would help identify frontal features. Unfortunately the unit apparently malfunctioned, with the result that no useful data were obtained.

Temperature-salinity Profiles.--Twenty-nine profiles of temperature-salinity were obtained during the 23-30 August period. Station locations are plotted in Figure 1 and tabulated in Table 2. The westernmost stations were occupied first, the eastern stations last. Secchi depths were also recorded at these stations.

A Hydrolab model 4021 meter was used to measure temperature and conductivity at depths of (typically) 0, 2, 5, 7 and 10 m, and increasing 5 m intervals to the bottom or 50 m. The Hydrolab instrument employs a thermistor to measure temperatures to within 0.2°C of their true values (manufacturer's specifications). A four-electrode conductivity cell measures the in-situ water conductivity which is then adjusted internally to a standard 25°C reference temperature. Depths were determined from the wire out through a metre block.

The temperature compensation electronics of the Hydrolab did not function properly during this project. Measured conductivities were unrealistically low and the error appeared to be time dependent. Salinities computed within the main subsurface portions of the Arctic Water Layer, at about 50 m depth, were only 11 to 19 parts per thousand (°/oo), whereas they should have been on the order of 32°/oo. Consequently, little use could be made of the salinity data. The salinity profiles have been included with the plots of the temperature data because comparisons of data from nearby stations may indicate relative changes which occurred during that time interval. Comparisons should not be made between stations that differed significantly in time. For example, the profiles at stations 26 and 27, where whales were feeding and not feeding, respectively, differ by about one hour. The data indicate lower salinity water at station 26 than at 27, and this is probably believable although the absolute salinity values are meaningless.

A post-calibration of the temperature sensor on the Hydrolab unit showed it was reading 0.2°C too low. After applying this correction, the measured temperatures at 30-50 m offshore in the upper portion of the Atlantic Water Layer were consistently near -2.0°C. As this value is less than the freezing temperature of the waters typically found at these depths (for salinity values of about 32°/oo), the Hydrolab temperatures were further

Table 2. Temperature-salinity profiles obtained 23-30 August, 1985, using a Hydrolab model 4021.

Station	Date in Aug.	Time (GMT)	Latitude	Longitude	Depth (m)		
					Water	Secchi	Data*
Transect 5							
25	23	1804	69.47.1	138.24.7	171	4.0	50
24	"	1928	69.43.2	138.33.1	(157)**	3.7	50
23	"	2119	69.39.2	138.41.5	81	3.4	50
22	"	2258	69.36.0	138.49.9	12	3.1	7
21	"	2337	69.34.7	138.50.4	7	1.8	5
Transect 4							
20	25	1906	69.36.2	138.27.1	131	1.4	35
19	"	2141	69.32.0	138.35.0	39	2.3	30
18	"	2312	69.28.2	138.43.6	17	3.4	15
17	26	22	69.24.1	138.51.9	11	2.0	7
16	"	57	69.23.4	138.53.2	8	.8	5
Transect 3							
15	27	1917	69.30.5	137.55.7	57	.9	50
14	"	2152	69.26.5	138.04.1	64	.9	50
13	"	105	69.22.5	138.12.4	52	1.2	50
12	26	1550	69.18.6	138.21.2	11	1.5	9
11	"	1641	69.17.7	138.20.9	7	1.5	5
Transect 2							
10	30	2130	69.18.8	137.32.4	40	1.8	35
9	"	1703	69.15.7	137.42.5	34	1.8	30
8	29	2300	69.10.8	137.49.5	31	10.5	25
7A	28	2122	69.07.3	137.59.8	12	2.1	10
7B	29	2136	69.07.3	137.59.8	11	5.2	9
6	28	1928	69.06.9	138.01.2	8	2.3	6
Transect 1							
5	30	1915	69.16.1	137.20.4	21	2.6	20
4	"	1433	69.12.3	137.28.7	21	1.7	18
3	"	156	69.08.0	137.37.5	21	1.5	18
2	29	120	69.04.5	137.46.9	13	2.3	10
1	28	2348	69.01.6	137.38.0	8	1.4	5
Whale Feeding Area							
26N	29	1706	69.16.3	138.16.2	25	2.6	20
26S	"	1728	69.16.3	138.16.2	19	2.4	15
Control Area							
27	29	1816	69.16.5	138.11.5	34	12.0	30

* Maximum depth for temperature-salinity profile.

** Water depth at station 24 was estimated from a nautical chart.

increased by 0.4°C (making the correction to the raw data +0.6°C). The corrected 30-50 m temperatures were now on the order of -1.5 to -1.6°C; this is consistent with the temperature-salinity data collected by Hopky et al. (1986) in the same area on 24-26 July, 12 August and 7-10 September 1985.

Net Sampling of Plankton

Net sampling was conducted at 25 stations along five transects, at one additional station where bowheads were apparently feeding, and at a nearby control station where no bowheads were present (see Figure 1 for station locations and Table 3 for sampling details). Fifty-nine plankton samples were collected.

Oblique Bongo Tows.--Oblique zooplankton samples were collected using a bongo frame (Posgay and Marak 1980) fitted with two nets (mesh size 0.5 mm) and a flow meter (General Oceanics, model 2030). Two of 16 oblique tows were made with nets 20 cm in diameter, the remainder with nets 61 cm in diameter. Nets were towed at 1.04 m/s (SD = 0.16, N = 16). In waters over 25 m deep, oblique tows were made through the upper 25 m of the water column (N = 12); in waters between about 10 and 25 m deep, tows were made through the upper 10 m of the water column (N = 4). Nets sampled the water column during descent and ascent and tows were made for roughly equivalent periods of time (ca. 10 min).

Horizontal Bongo Tows.--Two types of horizontal tows were made with the 61 cm bongo frame assembly. At 20 stations, nets were towed just below the surface (estimated depth of 1 m) for about 10 min at a speed of 1.21 m/s (SD = 0.05, N = 20). An additional 23 horizontal tows were made at varying depths down to 23.9 m. An upward looking depth-sounder transducer (Apelco Ranger model 1650) was attached to the bongo frame assembly in order to provide control of sampling depth. The transducer was hard-wired to a surface unit that provided both a hard-copy printout (Fig. 8) and a digital readout of sampling depth. The bongo frame was lowered to the desired depth and towed for about 10 min before retrieval. Nets were towed at 1.20 m/s (SD = 0.15, N = 23). Nets sampled both on the descent to, and the ascent from, desired sampling depths. At the surface, nets sampled the nominal depth for 100% of the time. At the deepest depth sampled with a horizontal tow (24 m), the net sampled the nominal depth for only 56% of the time.

Drop Net Samples of Epibenthos.--A modified drop net sampler 0.5 m in diameter and with a net 1 m long (1.0 mm mesh) was used to sample epibenthic invertebrates at inshore stations 1 (N = 9), 6 (9), 7 (1) and 11 (9). Griffiths and Dillinger (1981) describe the net and the sampling procedure.

Calorimetry and Lipid Sampling.--To determine the caloric content of zooplankton samples and size classes of certain groups of zooplankters, the samples from one of the two nets on the bongo assembly were frozen. Subsamples were sent to the Water Analysis Facility, Memorial University, St John's, Newfoundland, for analysis. Some frozen material was sent to Dr. A. Place, Department of Biology, University of Pennsylvania, Philadelphia, for analysis of lipid content and composition.

Table 3. Summary of plankton samples collected off the Yukon coast, 23-30 August, 1985.

	Sample						
Station	Number	Type*	Depth (m)	Water depth (m)	Date in August	Tow speed (m/s)	Cu. m water filtered
Transect 5							
Station 25	1	OB	25	171	23	.89	90.12
Station 24	2	OB	25	157	"	.98	111.42
Station 23	3	OB	25	81	"	1.06	102.19
	4	HD	6	"	"	1.09	191.28
Station 22	5	OB	10	12	"	0.82	56.06
Station 21	6	HS	1	6.5	"	1.15	198.37
Transect 4							
Station 20	7	OB	10	131	25	.62	12.62
	9	OB	10	"	"	.99	18.47
Station 19	10	OB	25	39	"	1.12	132.72
Station 18	11	OB	10	17	"	1.18	81.35
Station 17	12	HS	1	11	"	1.25	220.11
Station 16	13	HS	1	8	"	1.21	211.95
Transect 3							
Station 15	16	OB	25	57	27	1.1	181.64
	17	HS	1	"	"	1.15	202.02
	18	HD	4.2	"	"	1.26	221.55
	19	HD	8	"	"	1.15	214.65
Station 14	20	HD	7.9	64	"	1.43	263.03
	22	HS	1	"	"	1.21	207.74
	23	HD	21.1	"	"	1.43	452.9
	24	OB	25	"	"	1.14	185.89
Station 13	25	OB	25	52	"	1.26	242.86
	26	HS	1	"	"	1.23	210.52
	27	HD	6.5	"	"	1.07	187.45
Station 12	14	HS	1	11	26	1.30	230.18
Station 11	15	HS	1	7	"	1.23	218.19
Transect 2							
Station 10	57	HS	1	40	30	1.17	208.99
	58	HD	4.8	"	"	1.17	207.81
	59	HD	8.9	"	"	1.22	219.15
	60	HD	16.2	"	"	1.07	197.91
	61	OB	25	"	"	1.11	197.76
Station 9	49	HS	1	34	"	1.13	194.36
	50	HD	8.3	"	"	1.05	192.79
	51	OB	25	"	"	.99	175.75

---

* Samples were obtained from three types of net tows: oblique tows (OB), horizontal tows near the surface (HS) and horizontal tows at depth (HD).

Continued...

Table 3. Concluded.

	Sample						
Station	Number	Type*	Depth (m)	Water depth (m)	Date in August	Tow speed (m/s)	Cu. m water filtered
Station 8	38	HS	1	31	29	1.26	222.58
	39	HD	8.3	"	"	1.10	205.04
	40	HD	23.9	"	"	1.11	342.69
	41	OB	25	"	"	1.16	216.52
Station 7	29	HS	1	12	28	1.17	205.16
	37	HD	7.1	11	29	1.13	201.22
Station 6	28	HS	1	8	28	1.23	223.54
Transect 1							
Station 5	52	HS	1	21	30	1.23	213.92
	53	OB	10	"	"	1.20	101.91
	54	HD	5	"	"	1.12	196.34
	55	HD	6.9	"	"	1.19	209.30
	56	HD	8.9	"	"	1.69	213.94
Station 4	45	HS	1	21	"	1.08	183.99
	46	HD	4.4	"	"	1.15	197.91
	47	HD	8.3	"	"	1.24	221.15
	48	HD	18.1	"	"	1.05	258.44
Station 3	42	HS	1	21	29	1.26	221.56
	43	OB	10	"	"	.98	63.63
	44	HD	8.6	"	"	1.30	246.26
Station 2	31	HS	1	11.7	28	1.20	213.29
	32	HD	7.7	"	"	1.17	209.85
Station 1	30	HS	1	6.5	"	1.25	219.29
Whale Feeding Area							
Station 26	33	HD	8.3	25	29	1.23	220.86
Control Area							
Station 27	35	HS	1	34	29	1.20	212.63
	36	HD	8.3	"	"	1.19	213.64

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* Samples were obtained from three types of net tows: oblique tows (OB), horizontal tows near the surface (HS) and horizontal tows at depth (HD).

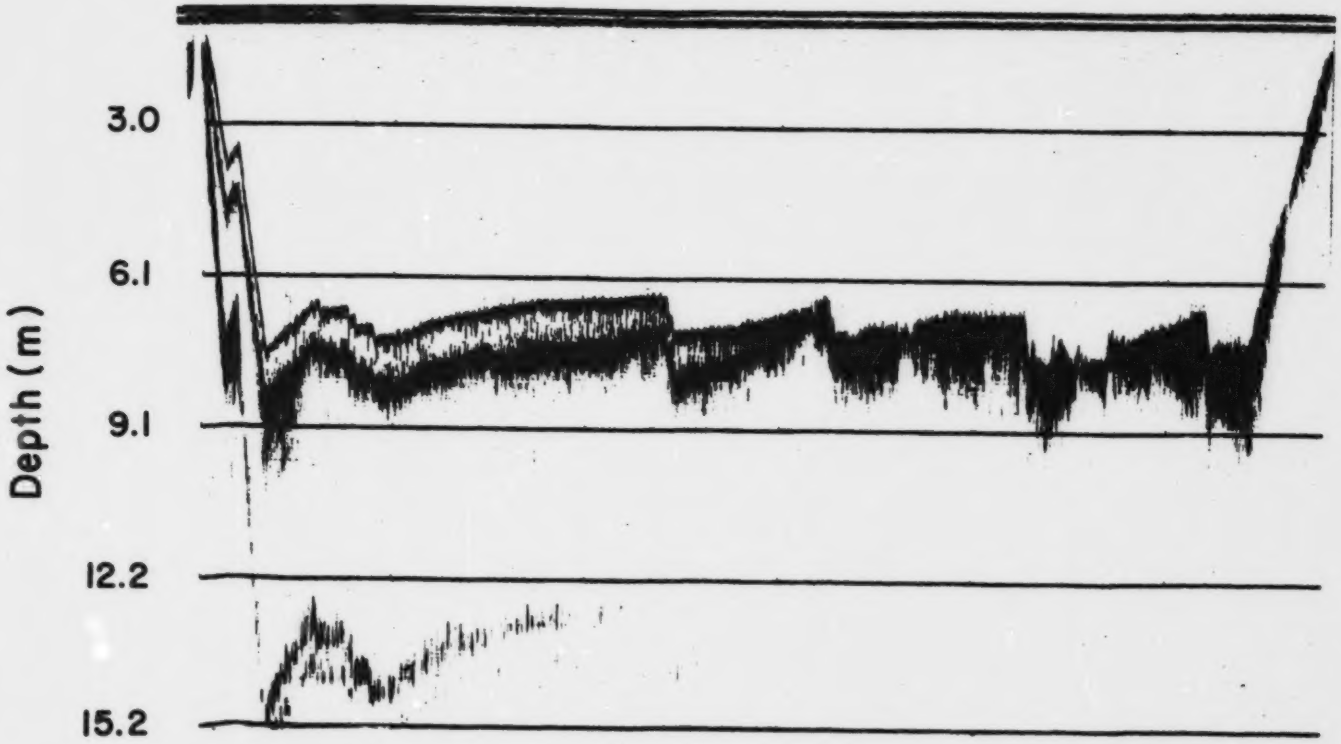


Figure 8. Apelco Ranger Model 1650 printout of sampling depth during a zooplankton tow at station 26 on 29 August, 1985 (sample number 33). Net was towed at 8.3 m for 10 min, and the upward-facing transducer provided an echogram of distance to the surface.

Hydroacoustic Sampling of Zooplankton

We attempted to delineate zooplankton concentrations with hydroacoustic observations made during zooplankton tows and while we steamed from station to station. We used a Ross Fine Line Depth Recorder (Model 250-M) and a multi-element, narrow beam transducer (200 kHz, 3.5° beam width, faired housing) mounted 1 m below the surface along the starboard side of the boat. Log records of date, time, paper speed, pulse length, depth range, sensitivity and fine line (a feature that enhances bottom detail) were kept during all hydroacoustic surveys.

Hydroacoustic data were collected with a 200 kHz narrow-beam transducer (1) during 37 of 59 zooplankton tows and (2) along varying portions of the transects between sampling stations. The 200 kHz narrow-beam system was chosen over the more conventional lower energy and wider-beam systems for two reasons. First, the 200 kHz system receives a stronger return from medium-sized zooplankters (e.g. copepods) than does a lower energy system. Second, the narrow beam transducer increases the depth penetration of the high-energy signal over that achieved with wide-beam transducers. Energy return was recorded as hardcopy echograms.

Laboratory Analysis

Zooplankton.--All samples collected for species determinations were preserved in 5-10% buffered formalin in the field and shipped to the laboratory for analysis. Samples were sieved through a 0.25 mm mesh nylon screen, washed with water, and examined under a low-power microscope. Individual items were identified to species where possible, counted and wet-weighed by taxon to the nearest mg using a Mettler PT 200 electronic balance. If large numbers of organisms were present, which was usually the case, rare and large items were first removed from the sample and processed, and then the remainder of the sample was subsampled with a Folsom Plankton Splitter (McEwen et al. 1954; Griffiths et al. 1984). Items in the subsample were then processed and subsample data were applied to the whole sample to estimate total numbers and weights. Copepods were frequently subsampled a second time with a Hensen-Stemple pipette. In the 59 cases involving the subsampling of copepods, a mean of 661 copepods per sample (SD = 307, range 111 to 1518) were fully processed. Copepods were identified to life-stage.

When less than 10 zooplankters of a given taxon and life-stage were present in a sample or subsample, all were measured. When larger numbers were present, 10 were randomly selected. The cephalothorax lengths of copepods were measured to the nearest 0.1 mm on a stage micrometer and the total lengths of other zooplankters were measured to the nearest 0.5 mm on a measured rule.

Calorimetric Determinations.--Frozen material was split into two subsamples. One subsample (thawed and drained) was used to estimate the average caloric content of the sample as a whole. It was blended and dried to a constant dry weight at 70°C (about 18 h). The other subsample was used as a source of specific taxa of specific sizes. Since freezing and thawing can cause cell lysis and a consequent loss of body fluid, care was used to select turgid and minimally-damaged animals. Items were then sorted into 'small' and 'large' categories (for copepods these categories were <1.8 mm and > 4 mm; for mysids and Parathemisto <15 mm and 15+ mm; and for euphausiids and young-of-the-year gadids <20 mm and 20+ mm). We had hoped to obtain energetic determinations on moderately-sized copepods (1.81-4.0 mm) but too little material was found. Measurement techniques were those described above.

Once dried to a constant dry weight, samples were processed in a Parr high pressure oxygen bomb calorimeter.

Lipid Fraction Determinations.--Lipids were extracted from the frozen zooplankton samples following the methods of Bligh and Dyer (1959). An aliquot of extract was then dried to a constant mass at 40-50°C. From this information the percentage of sample dry weight consisting of lipid was calculated.

The remainder of the extract was dried under nitrogen. Measured amounts of the dried lipid (200-500 mg) were then loaded onto silica acid columns. Each column was eluted under nitrogen with successively more polar solvents (Nevenzel et al. 1965). These progressively more polar solvents dissolved different classes of lipids. Each of four lipid classes present in the samples (wax esters, triacylglycerols, fatty acids and complex lipids) were collected separately, again dried under a stream of nitrogen, re-dissolved in chloroform:methanol (2:1 by volume) and filtered through glass-fibre filters. Solvents were evaporated under nitrogen before final weighing and determination of the the total amount of lipid comprised by each class. Phospholipid content in each sample was determined in a separate analysis following the methods of Petitou et al. (1978). The quantity of each of the five classes of lipid thus extracted was expressed as a percentage of the amount of lipid loaded on the column.

Data Processing and Analysis

Hydroacoustic Data.--Only those segments of the echograms that were recorded with similar sensitivity and fine line controls were analyzed. During the data collection period (8 days), no obvious visual differences in the quality of the echograms could be discerned.

Forbes and Nakken (1972) noted that zooplankton abundance is proportional to the squared value of the intensity of registration on the echogram. We established a system of visually grading the echograms against 'standards' that reflected increasing densities of echo. With care, this method can provide reasonably unbiased estimates of echo abundance (Forbes and Nakken 1972).

The standard against which echograms were compared consisted of a 10-level (0-9) ordinal scale graduated by echo density. For each of the 10 levels, three examples were selected from locations where echo (zooplankton) density appeared similar (Fig. 9). Each segment corresponded to a 1 m depth interval and a 10 min time interval (approximately the period of one zooplankton tow).

It was important to test whether an observer could repeatedly assign a given segment to the same standard category. Each of the 30 standard echogram segments was mounted on a white card, uniquely numbered overleaf,

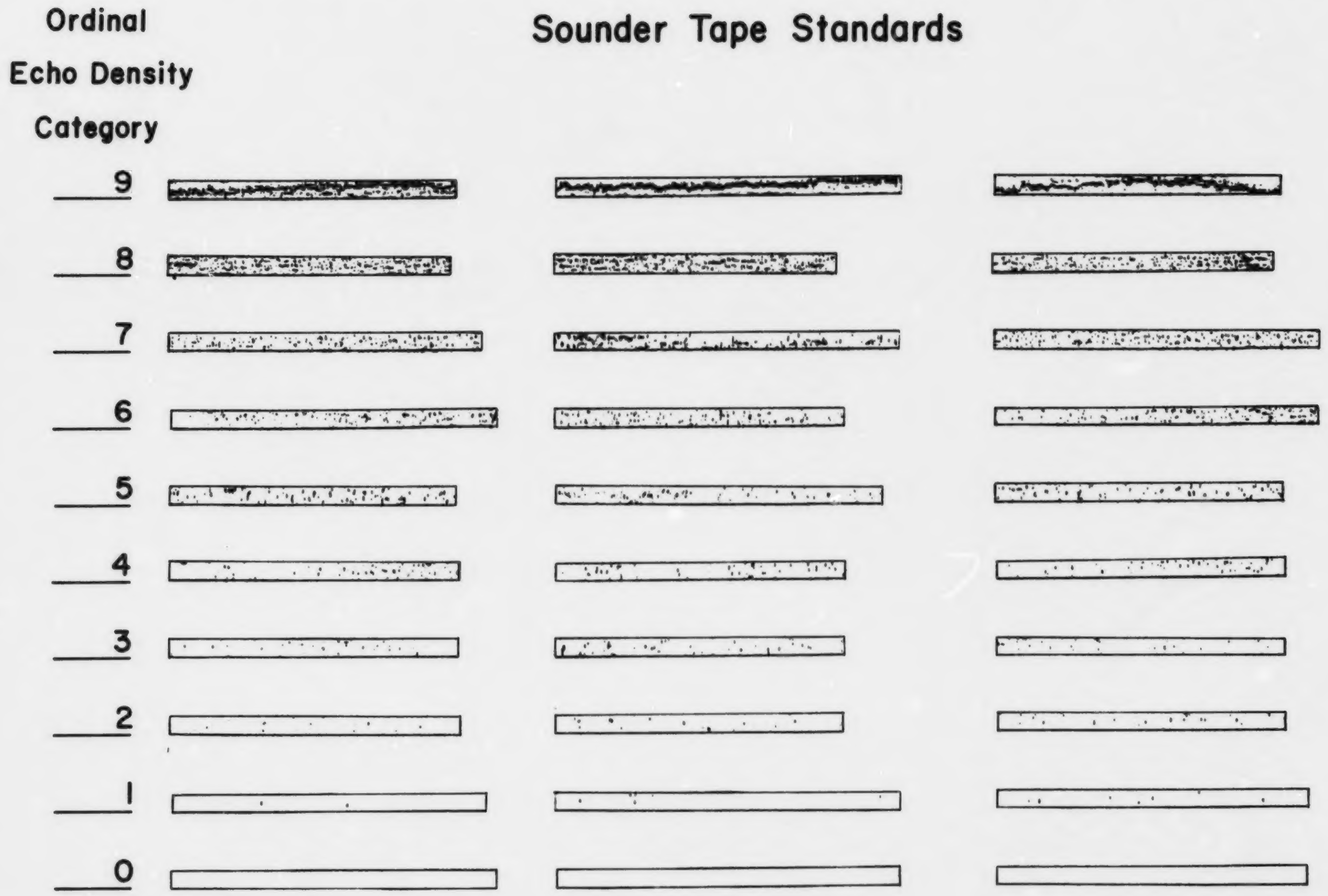

Sounder Tape Standards
Ordinal
Echo Density
Category
9
8
7
6
5
4
3
2
1
0

Figure 9. Standards used to estimate density of registration on echograms. For each standard level on the 0-9 ordinal scale, three examples are given.

and shuffled with 120 other cards, similarly-prepared. The 150 cards were then assigned to the 10 density classes and the identifying numbers recorded. The cards were re-shuffled and the process repeated.

In the two trials, 23% and 20% of the standard segments were incorrectly assigned to density class. In all cases, however, incorrect assignments were within one density class of the standard or originally-assigned value. Given the large number of density classes used (10 classes), and the small error in density assigned, we felt that the method was of general applicability in scaling the density of echogram segments.

A jig was designed to restrict visual reference to one segment of sounder tape (1 m x 5 min or 1 m x 10 min) at a time. Each segment was assigned an ordinal density class by direct reference to Figure 9. For each segment assessed, zooplankton sample number or transect number, segment depth, echogram density, start and finish times, sounder sensitivity, depth scale, and paper speed were recorded.

In addition to the specialized Ross echosounder used for zooplankton studies, the boat was equipped with a standard depth sounder. When the boat sounder was operational, the Ross echograms were of marginal use due to signal interference; all affected segments were discarded from the analysis.

Zooplankton Data.--Results of analyses of zooplankton were entered into an Apple IIe microcomputer and standardized to density/m^3 and biomass (mg)/m^3. Flowmeter data were used to estimate the volume of water filtered. Zooplankton data were analyzed on the Apple IIe with appropriate statistical software.

Bowhead Whale Data

Aerial surveys of the distribution of bowhead whales in the study area, and elsewhere in the Beaufort Sea, were conducted from 18 to 24 August 1985. The locations of whales sighted during those surveys were available in Norton and Harwood (1986). In addition, locations of whales photographed in the study area during August by Cubbage and Calambokidis (1986) and Davis et al. (1986) were used to determine water depths where the whales occurred. Estimated whale lengths, determined through photogrammetry, were used to assess the length-frequency distribution of whales occurring in the study area.

PHYSICAL CHARACTERIZATION OF THE STUDY AREA

Regional Sea-ice Patterns

The distribution of sea-ice is a major factor in determining regional oceanographic conditions within the study area. Sea-ice distributions are subject to a very large degree of annual variability during the summer months (Brower et al. 1977). The normal pattern of ice clearing commences with breakup of the coastal band of landfast ice in late June and early July. Due to the proximity of the Yukon coastline to the Mackenzie River discharges, the warm river water assists in maintaining open-water conditions through most of Mackenzie Bay after breakup. However, considerable quantities of ice can occur to the west and offshore of Herschel Island at any time during the summer. Occasionally, strong westerly winds advect this ice eastward as extensive bands of sea-ice along the Yukon coastline.

In the summer of 1985, the offshore retreat of the pack ice was unusually slow in the easternmost portion of the Canadian Beaufort Sea, particularly in the broad area off the Tuktoyaktuk Peninsula and near the mouth of Amundsen Gulf (longitudes 125°W to 134°W). High concentrations of pack ice occurred within 50 km of the Tuktoyaktuk Peninsula throughout July and August (Fig. 10 and 11). During the first half of September, the pack ice edge retreated seaward to 75-100 km offshore (Fig. 12). Ice conditions in the eastern portion of the Canadian Beaufort Sea were worse during July to September 1985 than during any other summer (aside from 1974) over the 15-year period 1971 to 1985. Only in 1974 did ice conditions further limit the area of open water.

Ice conditions to the west of the Mackenzie Delta, including our study area, were good in comparison with the more easterly portions of the Canadian Beaufort Sea. Clearing of the pack ice from the Yukon and eastern Alaskan coastlines began in late July (Fig. 10). From mid-August to mid-September (Fig. 11B and 12), the area of open water exceeded median values for this time of year. Virtually no sea-ice was present within 75 km of the Yukon coastline throughout this period.

Wind Conditions

Regional wind patterns are particularly important to the physical oceanographic characteristics of the study area, through wind-driven advection of differing water masses (Thomson et al. 1986) and through the occurrence of coastal upwelling under easterly winds (Borstad 1985). Throughout August 1985, the winds blew predominantly from the east and southeast with less frequent occurrences from the westnorthwest and southwest sectors (Fig. 13). Over the period preceding and during shipboard operations, four wind events were noted at Shingle Point: moderate to strong southeasterly winds on 20-21 August; moderate northwesterly winds on 23 August; moderate easterly winds on 25 August; and strong winds on 28-29 August, veering from southeasterly to southwesterly. The winds measured in Herschel Basin (Fig. 13) were also dominated by easterly and southeasterly winds throughout August. (Note that although the wind speeds at Herschel Basin apparently were larger in amplitude than those at Shingle Point, part of this increase was due to the greater height of the wind speed sensor used for the ship-based measurements.) The sequence of wind events in Herschel

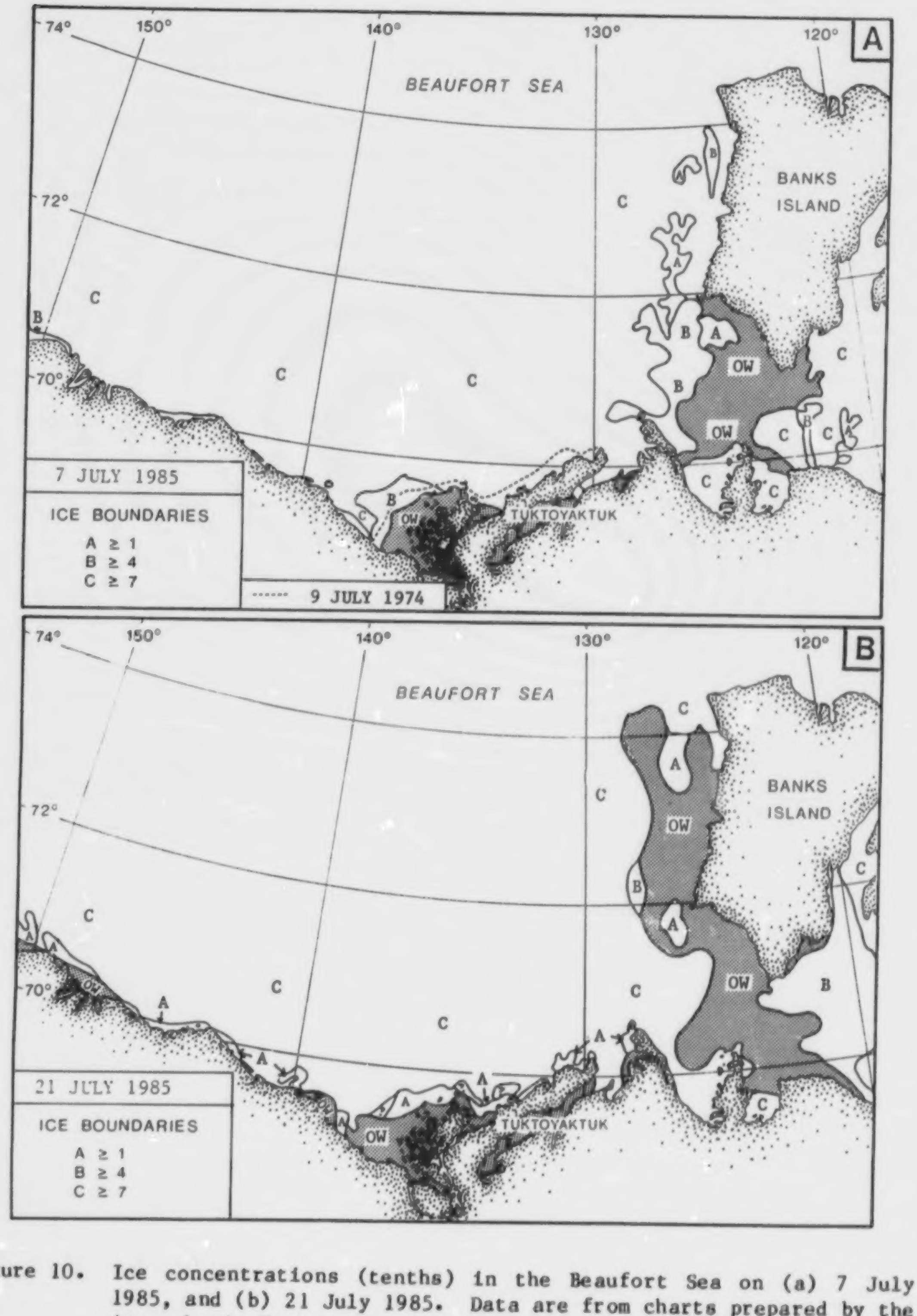

A
74°
150°
140°
130°
120°
72°
70°
BEAUFORT SEA
BANKS ISLAND
TUKTOYAKTUK
OW
A
B
C
7 JULY 1985
ICE BOUNDARIES
A ≥ 1
B ≥ 4
C ≥ 7
9 JULY 1974
B
74°
150°
140°
130°
120°
72°
70°
BEAUFORT SEA
BANKS ISLAND
TUKTOYAKTUK
OW
A
B
C
21 JULY 1985
ICE BOUNDARIES
A ≥ 1
B ≥ 4
C ≥ 7

Figure 10. Ice concentrations (tenths) in the Beaufort Sea on (a) 7 July 1985, and (b) 21 July 1985. Data are from charts prepared by the Atmospheric Environment Service, Ottawa. OW = Open Water.

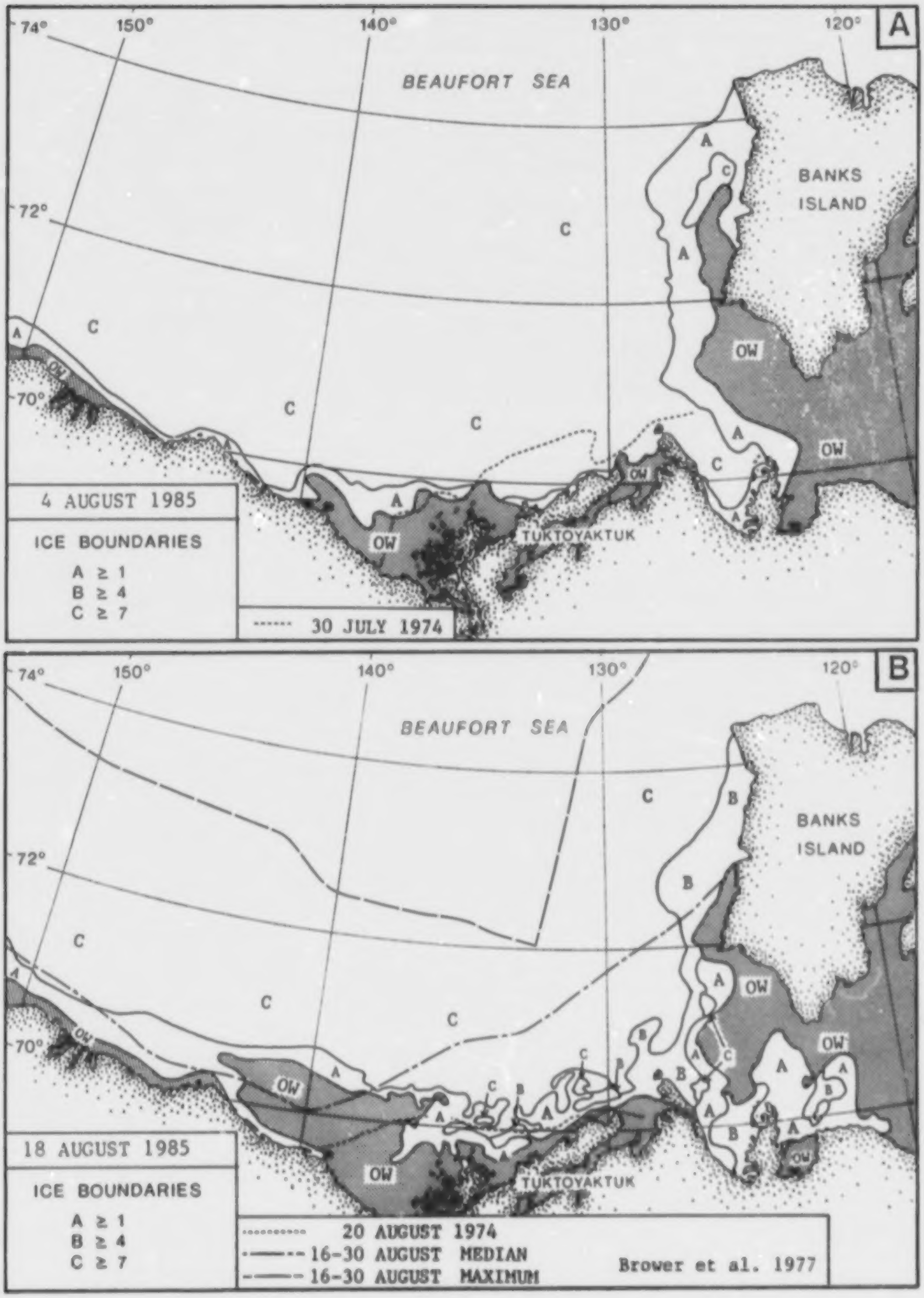

A
74°
150°
140°
130°
120°
BEAUFORT SEA
BANKS ISLAND
72°
70°
C
A
OW
TUKTOYAKTUK
4 AUGUST 1985
ICE BOUNDARIES
A ≥ 1
B ≥ 4
C ≥ 7
30 JULY 1974
B
18 AUGUST 1985
20 AUGUST 1974
16-30 AUGUST MEDIAN
16-30 AUGUST MAXIMUM
Brower et al. 1977

Figure 11. Ice concentrations (tenths) in the Beaufort Sea on (a) 4 August 1985, and (b) 18 August 1985 as compared to the 'extreme' ice year of 1974. Presentation as in Figure 10.

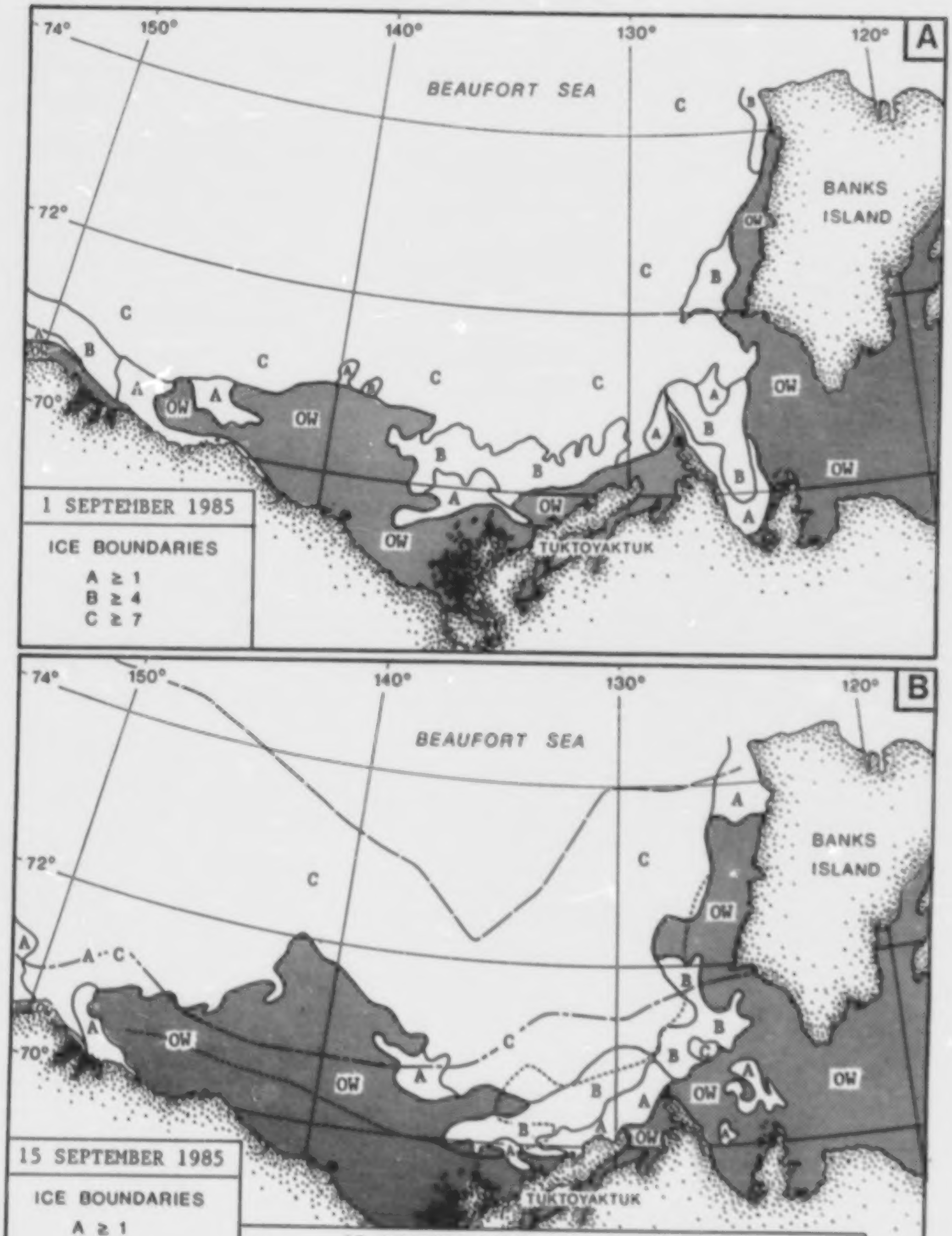

A
74°
150°
140°
130°
120°
72°
70°
BEAUFORT SEA
BANKS ISLAND
TUKTOYAKTUK
C
B
A
OW
1 SEPTEMBER 1985
ICE BOUNDARIES
A ≥ 1
B ≥ 4
C ≥ 7
B
15 SEPTEMBER 1985
10 SEPTEMBER 1974
16-30 SEPTEMBER MEDIAN
16-30 SEPTEMBER MAXIMUM
Brower et al. 1977

Figure 12. Ice concentrations (tenths) in the Beaufort Sea on (a) 1 September 1985, and (b) 15 September 1985 as compared to the 'extreme' ice year of 1974. Presentation as in Figure 10.

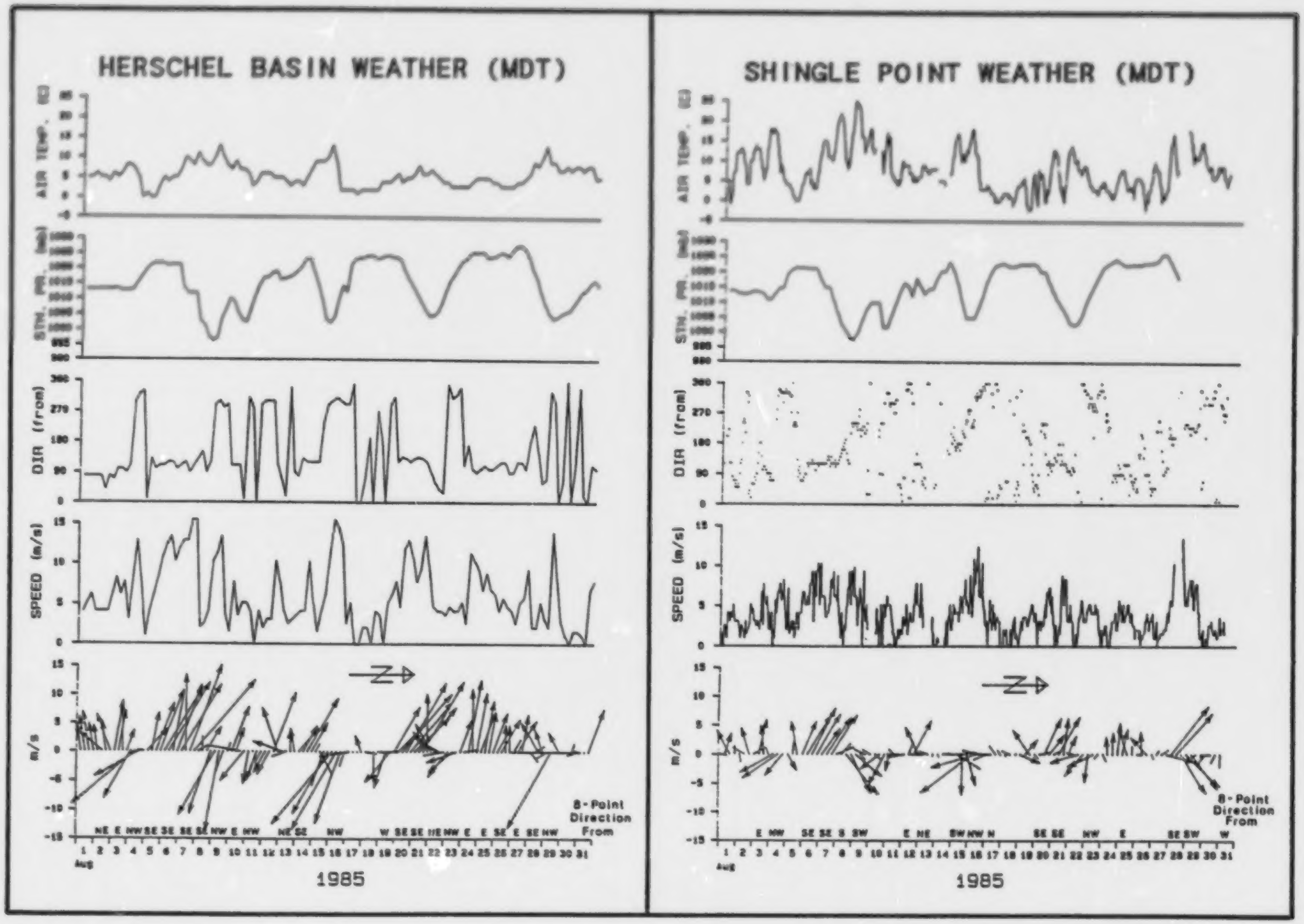


Figure 13. Meteorological conditions recorded at 6-h intervals from (a) ships located off the east coast of Herschel Island, and (b) the Atmospheric Environment Service weather station at Shingle Point. Times are presented as Mountain Daylight Time (GMT-6).

Basin during the latter half of August differed in some important respects from that of Shingle Point. While the first two wind events were reasonably similar at these sites, the following easterly wind event was of greater duration (24-26 August) and higher relative intensity at Herschel Basin than at Shingle Point. At Shingle Point, the fourth event on 28-29 August consisted of a strong southeasterly wind veering to southwesterly. During this period at Herschel Basin, there were local easterly winds on 28 August followed by a short period of strong northwesterly winds on 29 August.

Occasionally moderate to strong southwesterly wind events were observed at Shingle Point (9, 15 and 29 August), but not at Herschel Basin. During the occurrence of these southwesterly winds, the winds at Herschel Basin generally blew from the northwest. Coastal wind measurements obtained from 26 August to 14 September 1985 at King Point, located 35 km northwest of Shingle Point weather station, provide additional evidence of strong southwesterly winds blowing across the Yukon coastline (Fig. 14). The 28-29 August wind event at King Point consisted of strong westerly winds only, preceded by much weaker southeasterly winds on 27 August. Through the first half of September, three of the four large wind events observed at King Point blew from the southwest (6, 12 and 13 September). The occasional occurrence of strong but local southwesterly winds in the Shingle Point area is well known to pilots and others familiar with that area (W.J. Richardson, LGL Ltd., pers. comm.).

The presence of strong, southwesterly winds along the Yukon coastline at King and Shingle points indicates the occurrence of a fohn or 'chinook' wind (McIntosh and Thom 1969). This type of wind results from the flow of air downwards over the lee side of mountainous terrain, resulting in warm winds of considerable intensity. For the Yukon coastal areas, such winds appear to occur as downslope flows over the Richardson mountain range (Burns 1974) and may be confined to regions east of Kay Point.

Satellite Imagery

The six pairs of 'visible' and 'thermal' images, obtained from 18 to 28 August 1985 (Figs. 15-20), were analyzed to describe the general distribution of surface water properties as well as smaller scale features such as fronts and eddies.

In the images of 20-28 August, all three categories of surface water properties (intense plume, diffuse plume and arctic water) were present. Throughout the observation period, the intense plume was generally located to the east of the study area, which extended from Herschel Island to Shingle Point. A descriptive summary of the observed surface oceanographic features, along with the sequential changes in relation to prevailing winds, is presented below for Mackenzie Bay and the Yukon coastline.

Mackenzie Bay.--Throughout the latter part of August, the intense plume extended northwestward well into Mackenzie Bay, but was confined comparatively close to the shore towards the east, along the coastline of Richards Island and Kugmallit Bay. Such a distribution of intense plume water is consistent with the dominance of easterly winds throughout much of August, including the period of satellite observations. On 20 August, the offshore boundary of the intense plume water occurred as a pronounced front, found

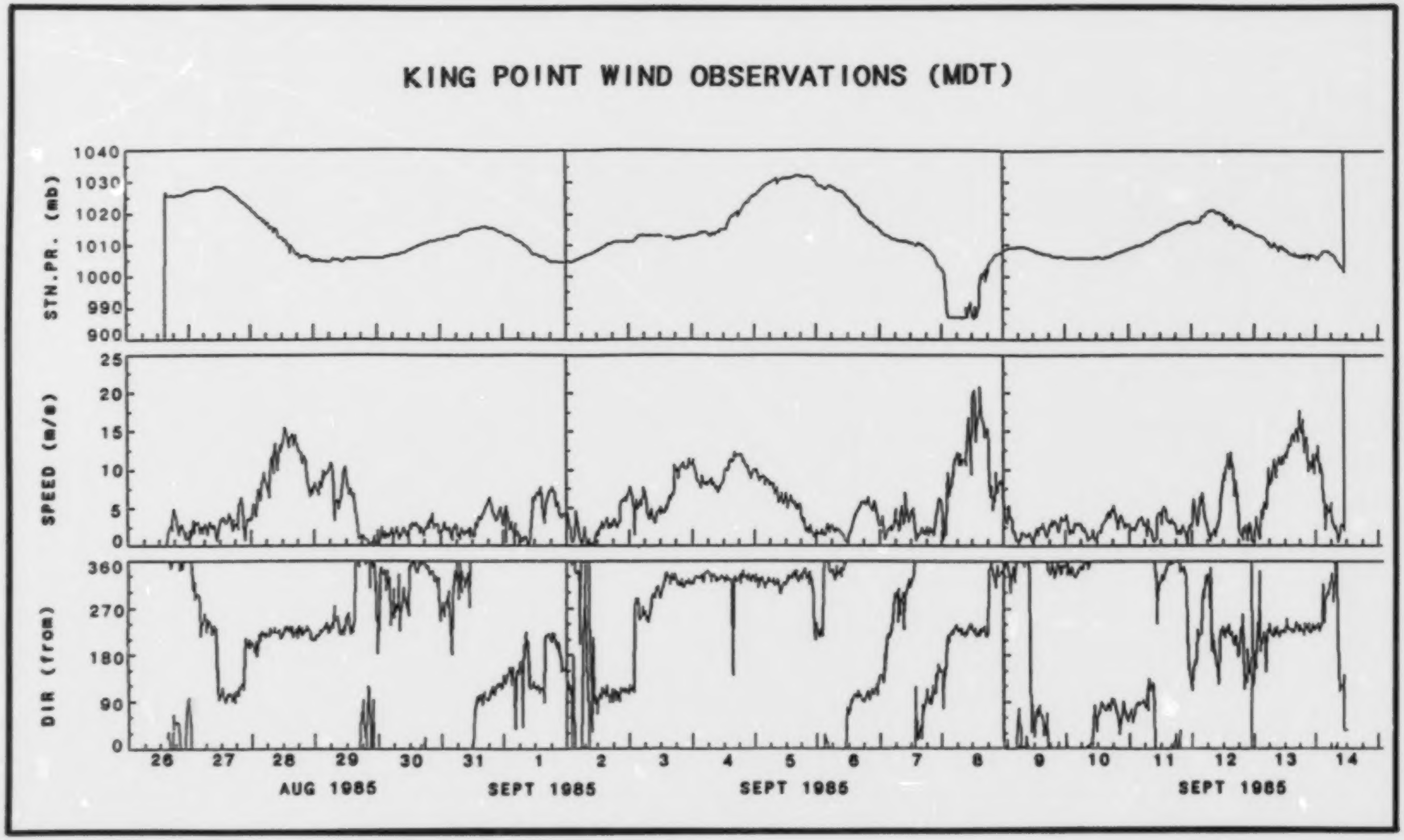


Figure 14. Air pressure, wind speed and wind direction measured at King Point, 26 August-14 September 1985. The wind data were recorded at 10 m elevation from the ground (Gillies, pers. comm.).

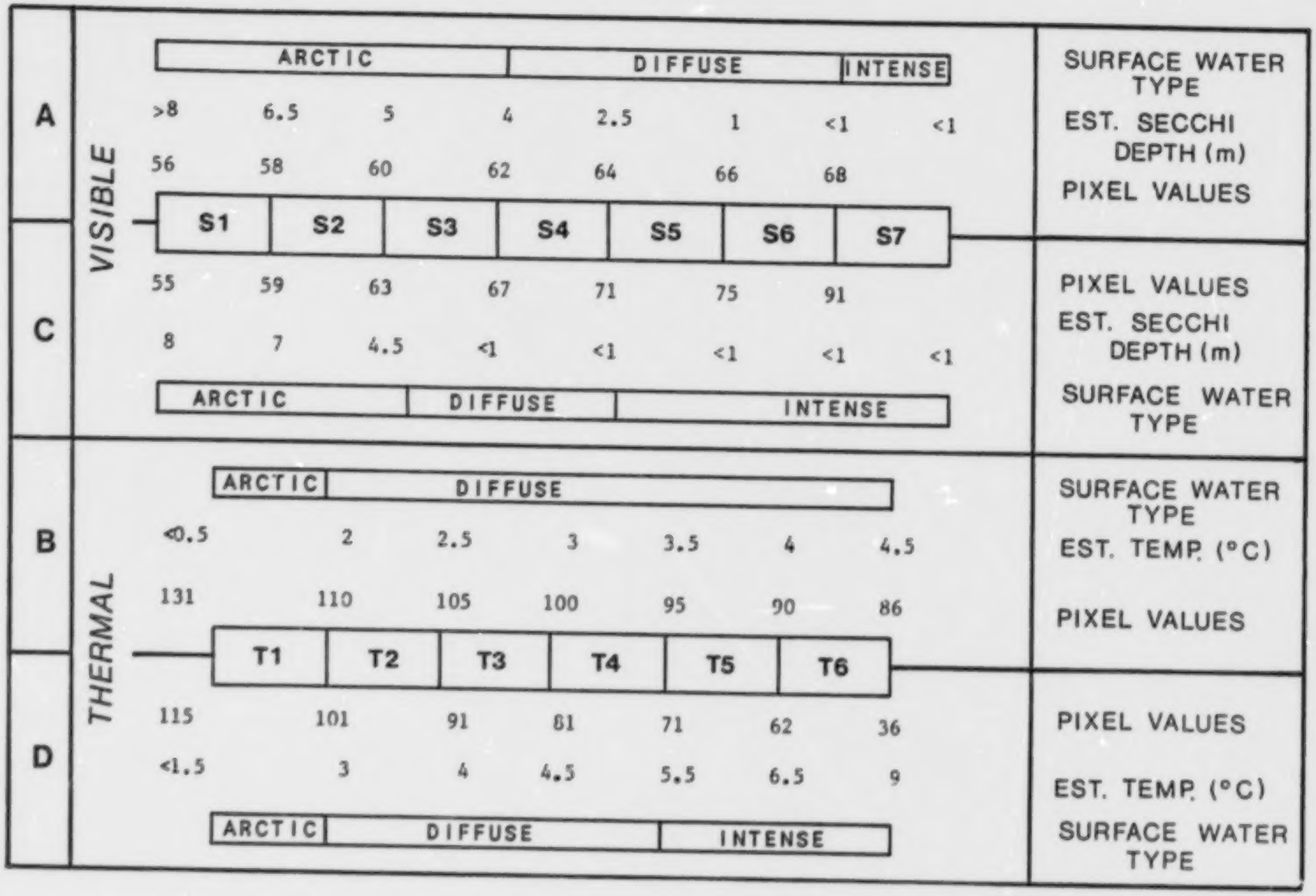
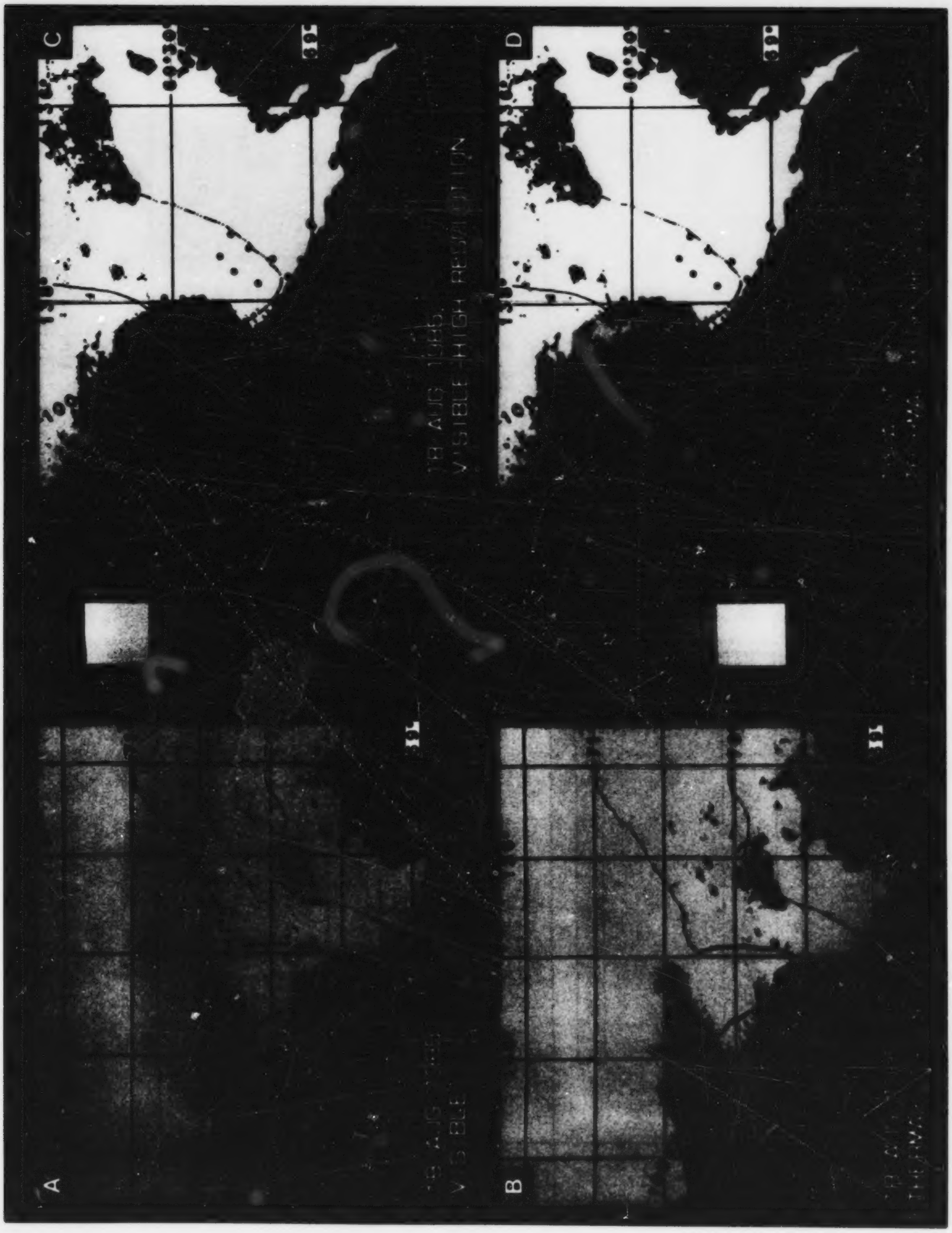

A
VISIBLE
ARCTIC
DIFFUSE
INTENSE
>8
6.5
5
4
2.5
1
<1
<1
56
58
60
62
64
66
68
SURFACE WATER TYPE
EST. SECCHI DEPTH (m)
PIXEL VALUES
S1
S2
S3
S4
S5
S6
S7
C
55
59
63
67
71
75
91
8
7
4.5
<1
<1
<1
<1
<1
ARCTIC
DIFFUSE
INTENSE
PIXEL VALUES
EST. SECCHI DEPTH (m)
SURFACE WATER TYPE
B
THERMAL
ARCTIC
DIFFUSE
<0.5
2
2.5
3
3.5
4
4.5
131
110
105
100
95
90
86
SURFACE WATER TYPE
EST. TEMP. (°C)
PIXEL VALUES
T1
T2
T3
T4
T5
T6
D
115
101
91
81
71
62
36
<1.5
3
4
4.5
5.5
6.5
9
ARCTIC
DIFFUSE
INTENSE
PIXEL VALUES
EST. TEMP. (°C)
SURFACE WATER TYPE

Figure 15. Satellite imagery for 18 August 1985 (1930 GMT) derived from the AVHRR sensor on the NOAA-9 satellite: (A) surface reflectance (band 1) from Alaska to the Mackenzie Delta; (B) surface temperature (band 4) from Alaska to the Mackenzie Delta; (C) surface reflectance (band 1) for the Yukon coastal area; (D) surface temperature (band 4) for the Yukon coastal study area. High-resolution plates (C,D) show locations of sampling stations as black dots.


A
B
C
D
18 AUG 1985
VISIBLE HIGH RESOLUTION
VISIBLE
THERMAL

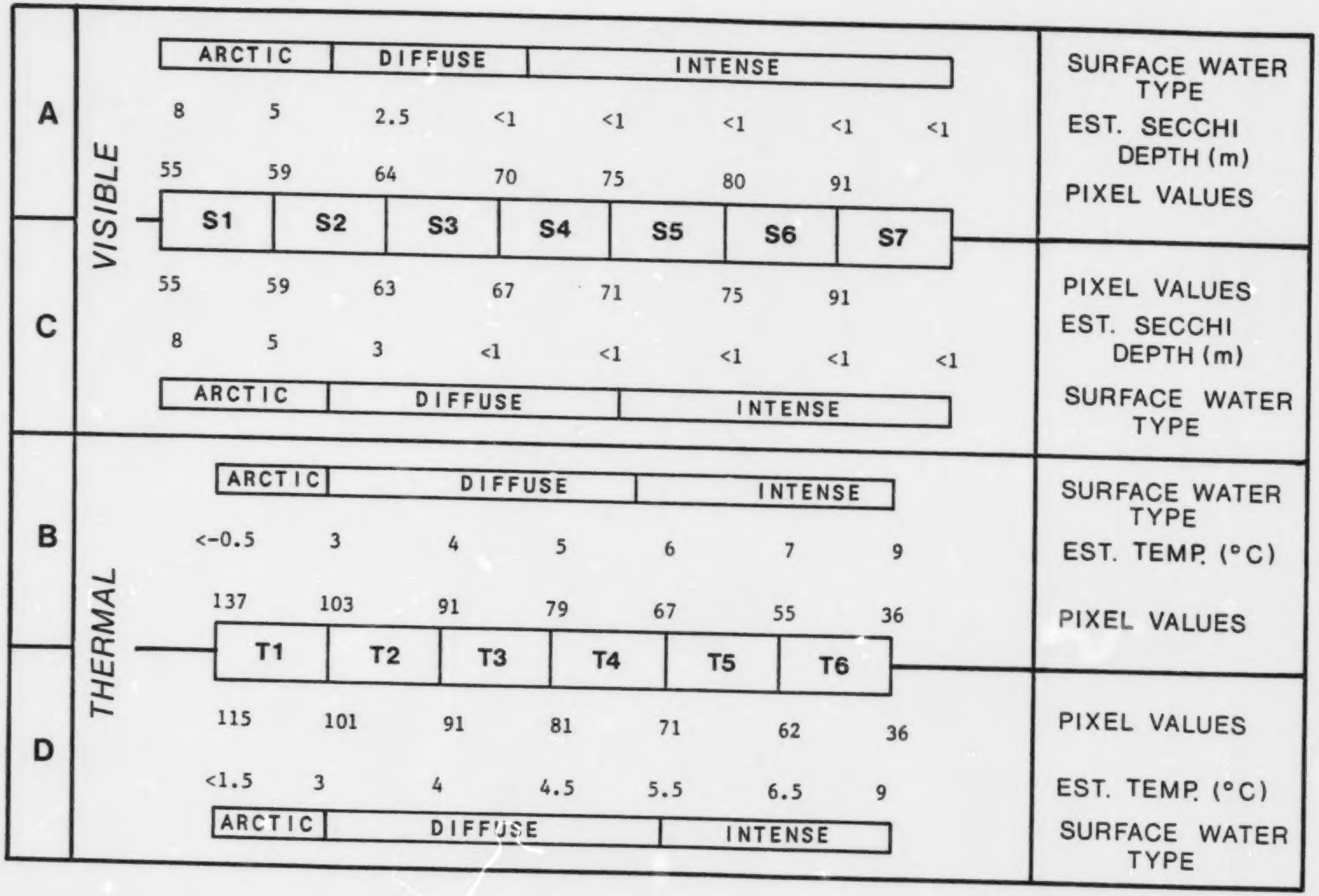
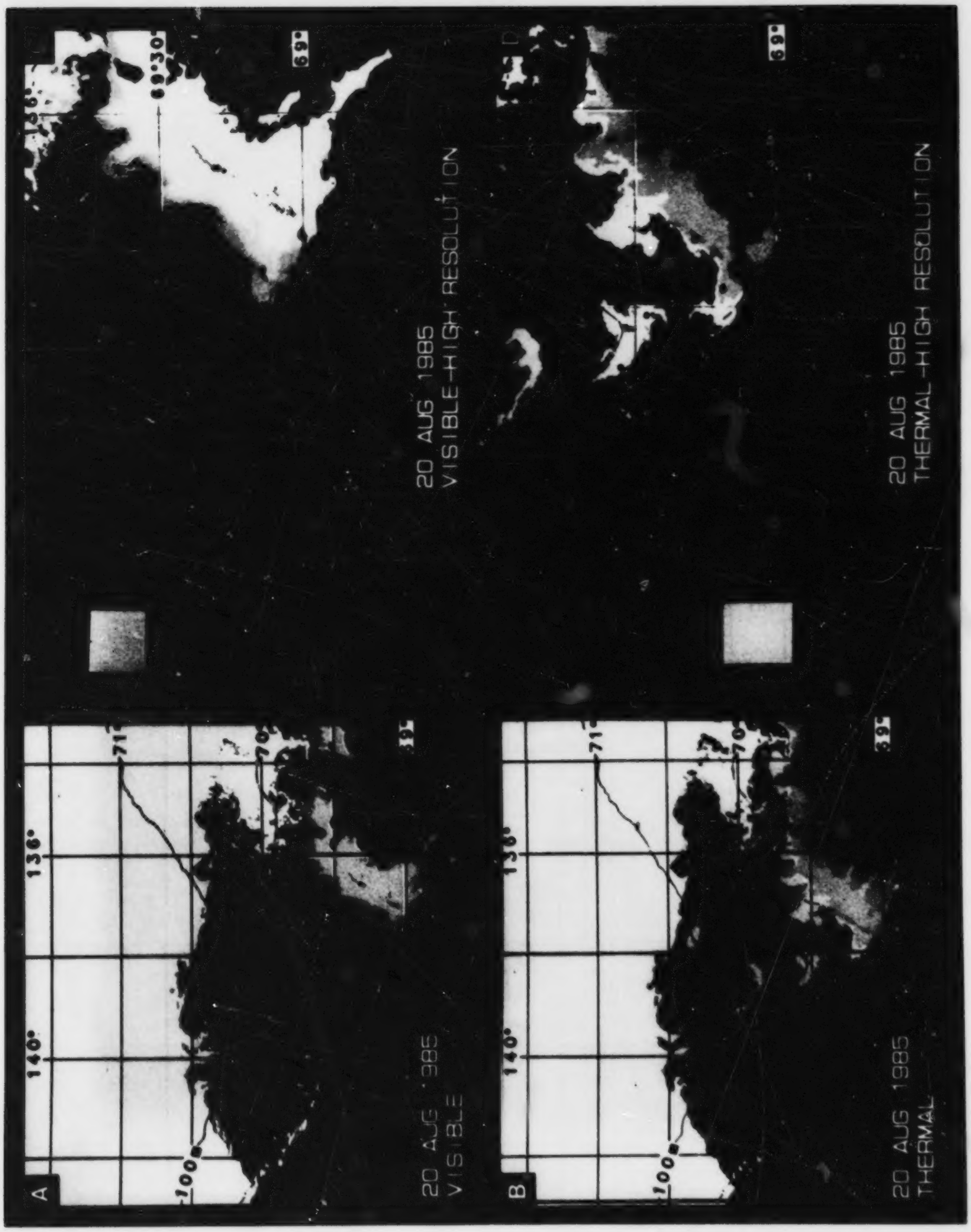

A
C
B
D
VISIBLE
THERMAL
ARCTIC
DIFFUSE
INTENSE
SURFACE WATER TYPE
8 5 2.5 <1 <1 <1 <1 <1
EST. SECCHI DEPTH (m)
55 59 64 70 75 80 91
PIXEL VALUES
S1 S2 S3 S4 S5 S6 S7
55 59 63 67 71 75 91
PIXEL VALUES
8 5 3 <1 <1 <1 <1 <1
EST. SECCHI DEPTH (m)
ARCTIC
DIFFUSE
INTENSE
SURFACE WATER TYPE
ARCTIC
DIFFUSE
INTENSE
SURFACE WATER TYPE
<-0.5 3 4 5 6 7 9
EST. TEMP. (°C)
137 103 91 79 67 55 36
PIXEL VALUES
T1 T2 T3 T4 T5 T6
115 101 91 81 71 62 36
PIXEL VALUES
<1.5 3 4 4.5 5.5 6.5 9
EST. TEMP. (°C)
ARCTIC
DIFFUSE
INTENSE
SURFACE WATER TYPE

Figure 16. Satellite imagery for 20 August 1985 (2117 GMT) derived from the AVHRR sensor on the NOAA-9 satellite. Presentation as in Figure 15.
]


A
20 AUG 1985
VISIBLE
B
20 AUG 1985
THERMAL
136°
140°
71°
70°
69°
100m
69°30'
20 AUG 1985
VISIBLE-HIGH RESOLUTION
20 AUG 1985
THERMAL-HIGH RESOLUTION

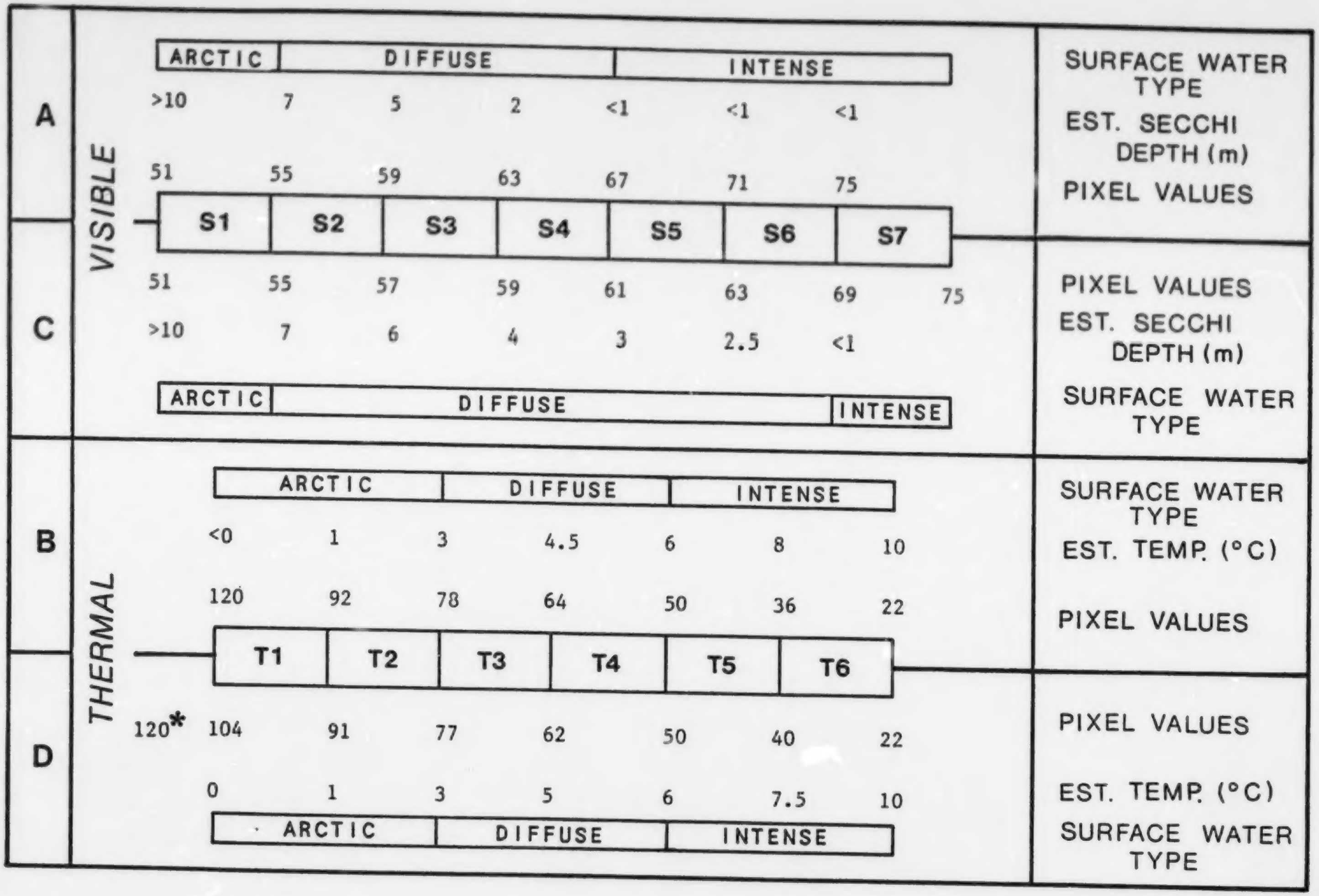
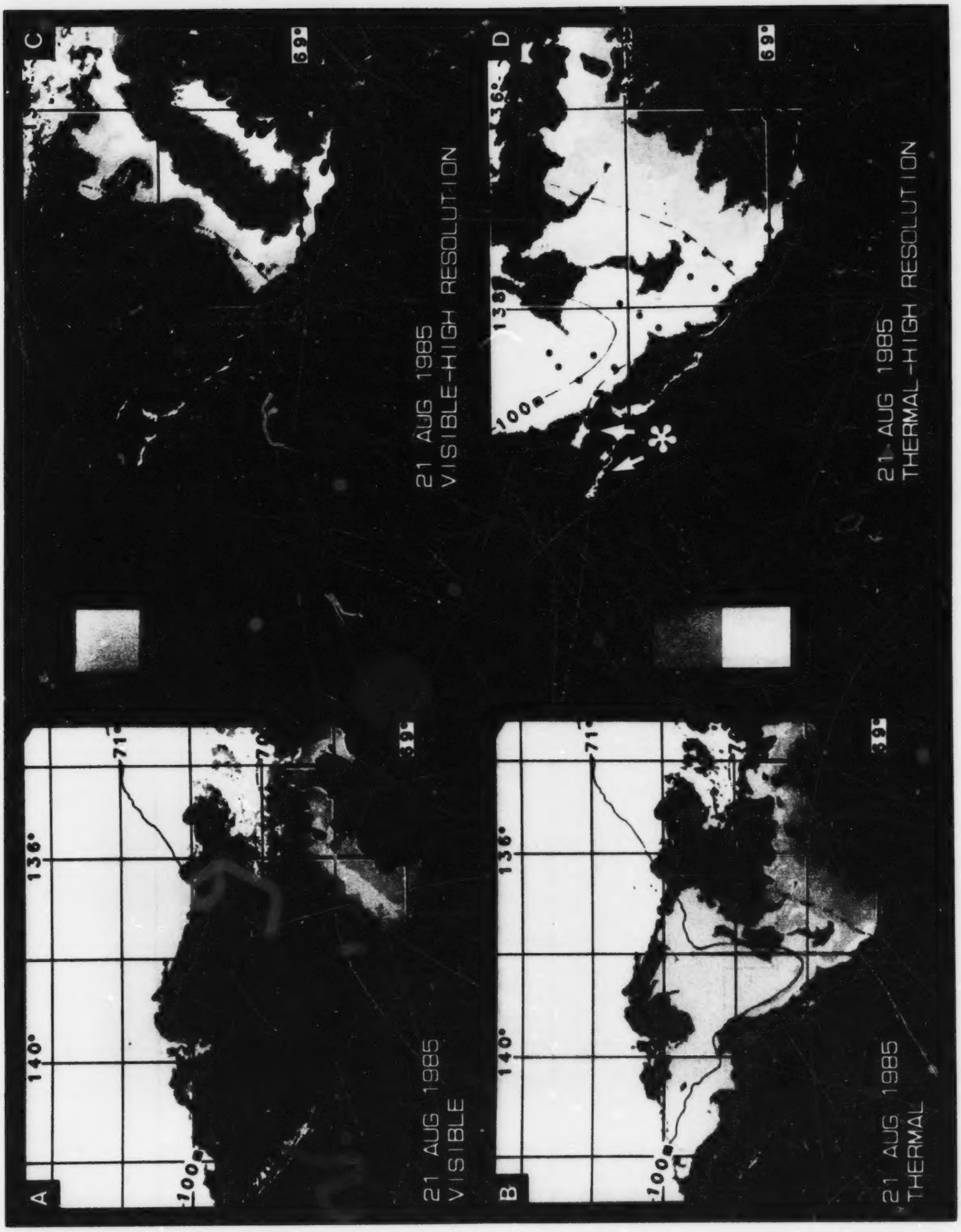

A
C
B
D
VISIBLE
THERMAL
ARCTIC
DIFFUSE
INTENSE
>10 7 5 2 <1 <1 <1
51 55 59 63 67 71 75
S1 S2 S3 S4 S5 S6 S7
51 55 57 59 61 63 69 75
>10 7 6 4 3 2.5 <1
ARCTIC
DIFFUSE
INTENSE
ARCTIC
DIFFUSE
INTENSE
<0 1 3 4.5 6 8 10
120 92 78 64 50 36 22
T1 T2 T3 T4 T5 T6
120* 104 91 77 62 50 40 22
0 1 3 5 6 7.5 10
ARCTIC
DIFFUSE
INTENSE
SURFACE WATER TYPE
EST. SECCHI DEPTH (m)
PIXEL VALUES
PIXEL VALUES
EST. SECCHI DEPTH (m)
SURFACE WATER TYPE
SURFACE WATER TYPE
EST. TEMP. (°C)
PIXEL VALUES
PIXEL VALUES
EST. TEMP. (°C)
SURFACE WATER TYPE

Figure 17. Satellite imagery for 21 August 1985 (1827 GMT) derived from the AVHRR sensor on the NOAA-8 satellite. Presentation as in Figure 15. Asterisk represents very cold water.


A
140°
136°
100m
71°
70°
69°
21 AUG 1985
VISIBLE
B
140°
136°
100m
71°
70°
69°
21 AUG 1985
THERMAL
C
69°
21 AUG 1985
VISIBLE-HIGH RESOLUTION
D
136°
138°
100m
69°
*
21 AUG 1985
THERMAL-HIGH RESOLUTION

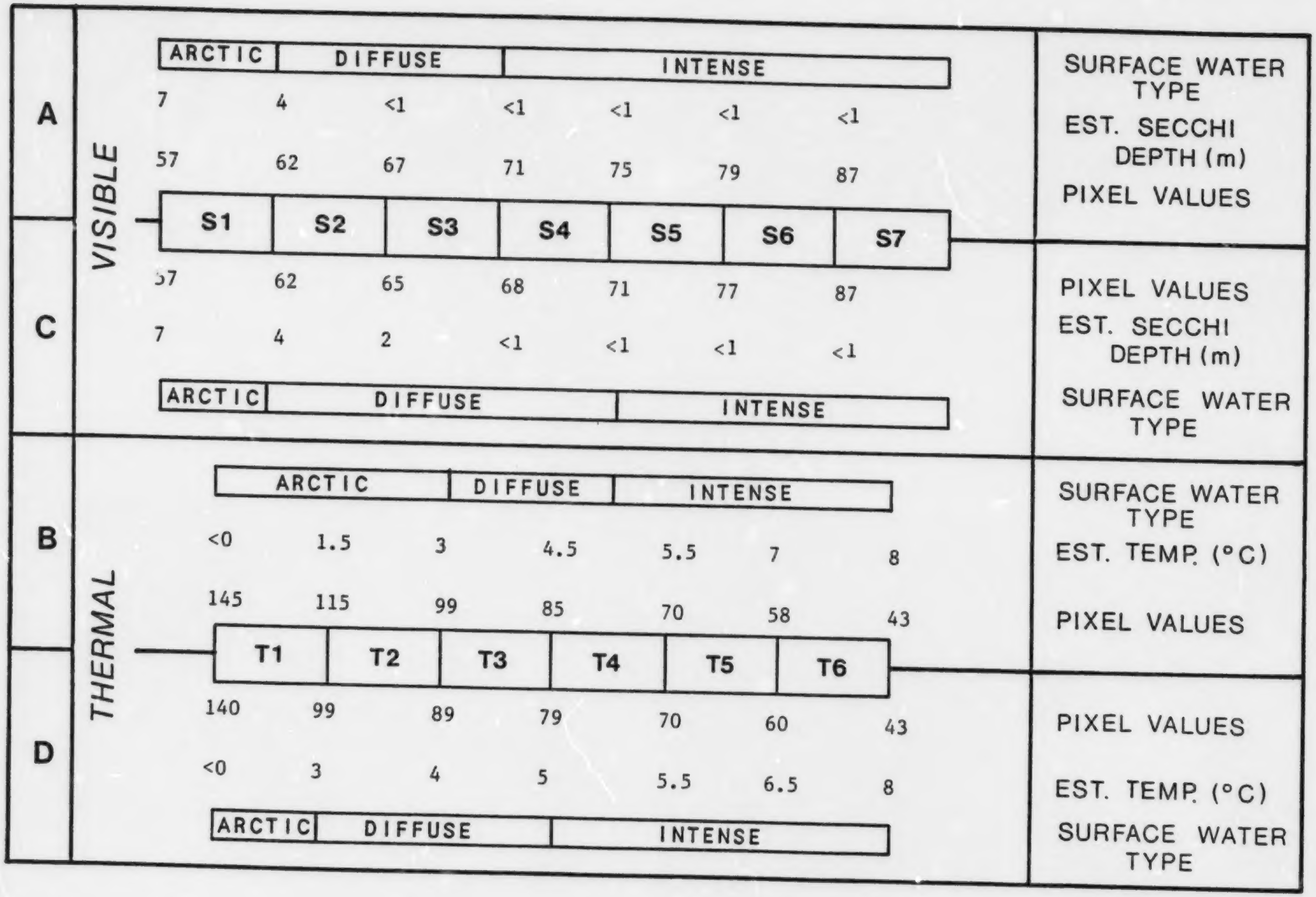
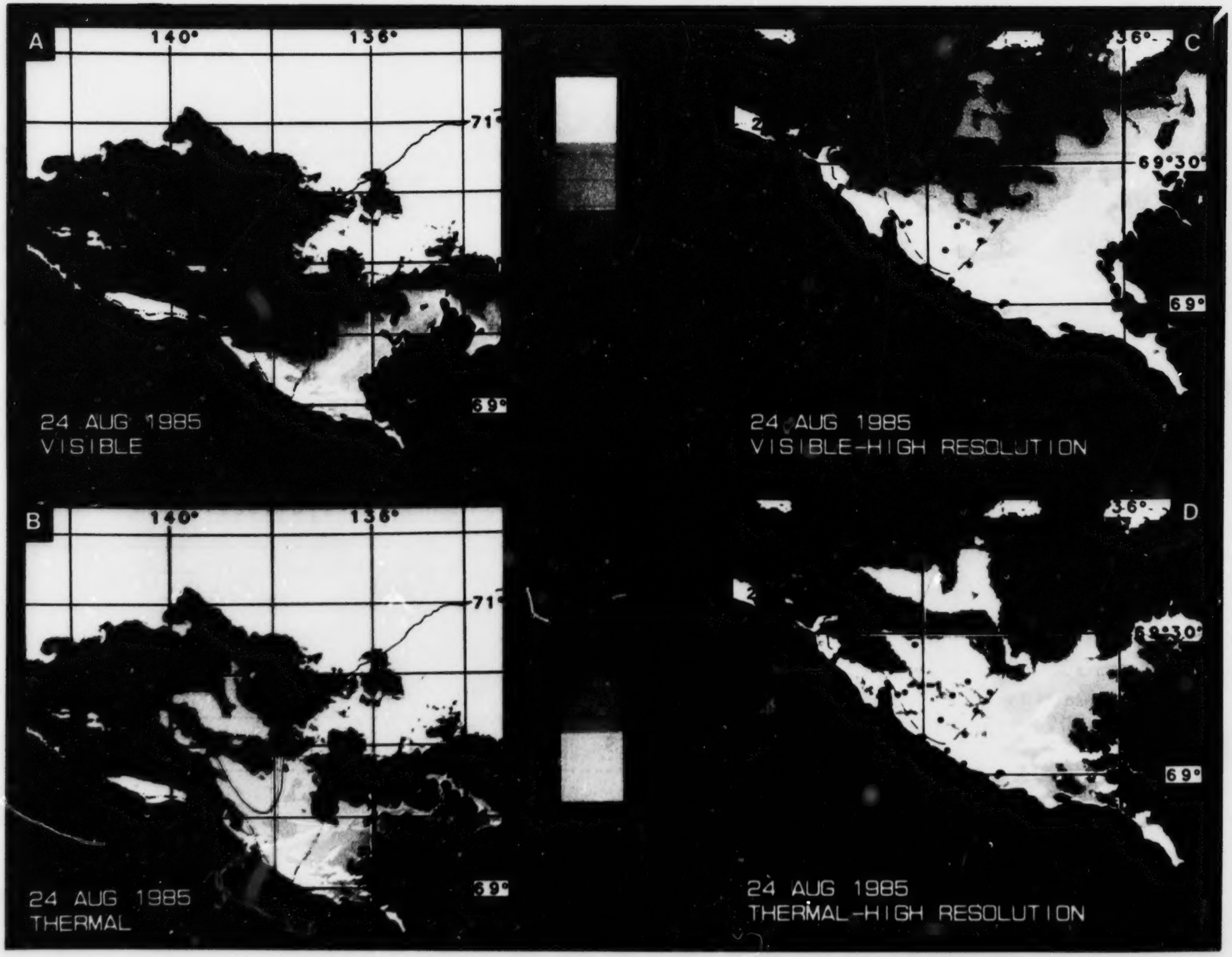

A
C
B
D
VISIBLE
THERMAL
ARCTIC
DIFFUSE
INTENSE
SURFACE WATER TYPE
7
4
<1
<1
<1
<1
<1
EST. SECCHI DEPTH (m)
57
62
67
71
75
79
87
PIXEL VALUES
S1
S2
S3
S4
S5
S6
S7
57
62
65
68
71
77
87
PIXEL VALUES
7
4
2
<1
<1
<1
<1
EST. SECCHI DEPTH (m)
ARCTIC
DIFFUSE
INTENSE
SURFACE WATER TYPE
ARCTIC
DIFFUSE
INTENSE
SURFACE WATER TYPE
<0
1.5
3
4.5
5.5
7
8
EST. TEMP. (°C)
145
115
99
85
70
58
43
PIXEL VALUES
T1
T2
T3
T4
T5
T6
140
99
89
79
70
60
43
PIXEL VALUES
<0
3
4
5
5.5
6.5
8
EST. TEMP. (°C)
ARCTIC
DIFFUSE
INTENSE
SURFACE WATER TYPE

Figure 18. Satellite imagery for 24 August 1985 (2216 GMT) derived from the AVHRR sensor on the NOAA-9 satellite. Presentation as in Figure 15.


A
140°
136°
71°
69°
24 AUG 1985
VISIBLE
B
140°
136°
71°
69°
24 AUG 1985
THERMAL
C
36°
69°30'
69°
24 AUG 1985
VISIBLE-HIGH RESOLUTION
D
36°
69°30'
69°
24 AUG 1985
THERMAL-HIGH RESOLUTION

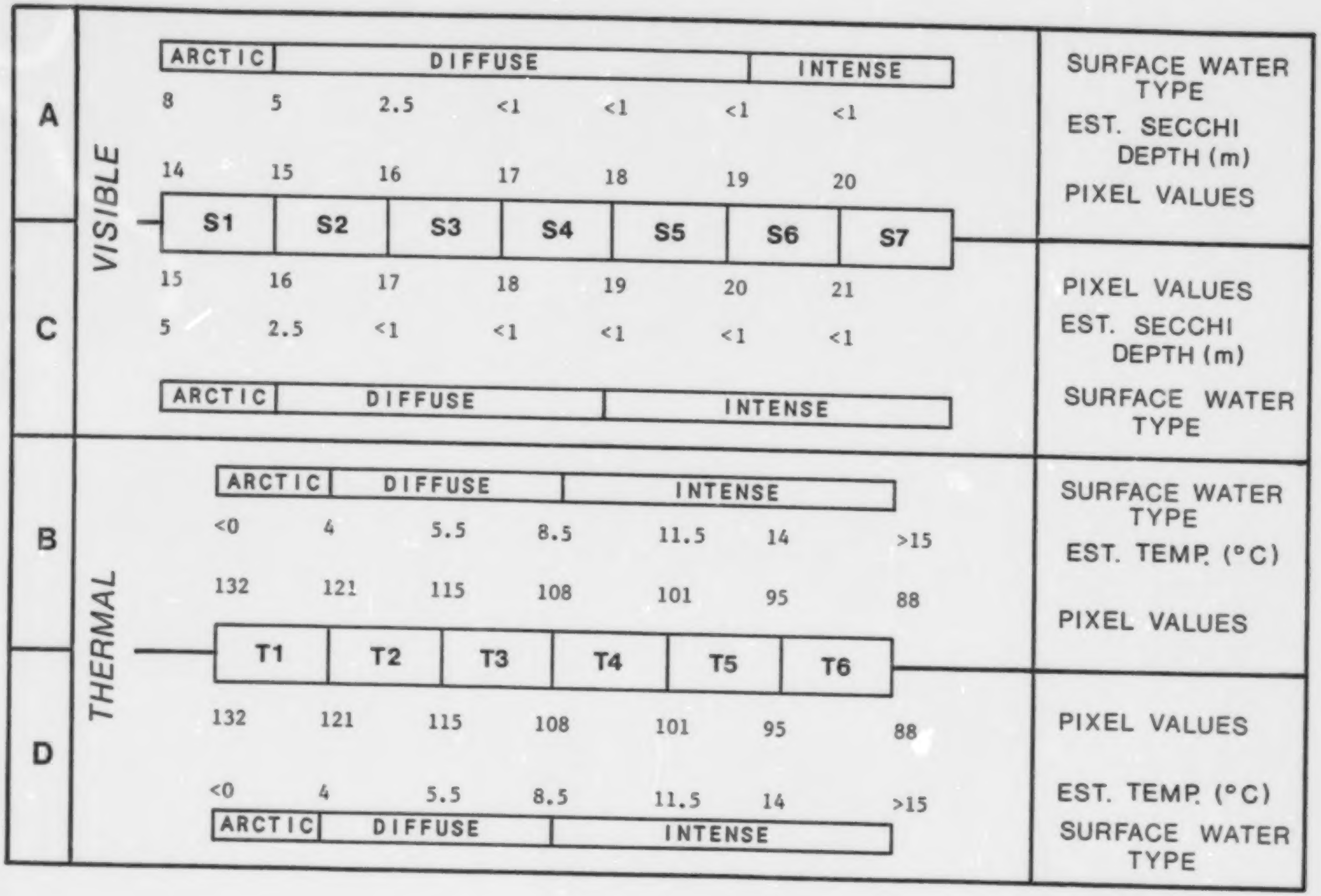
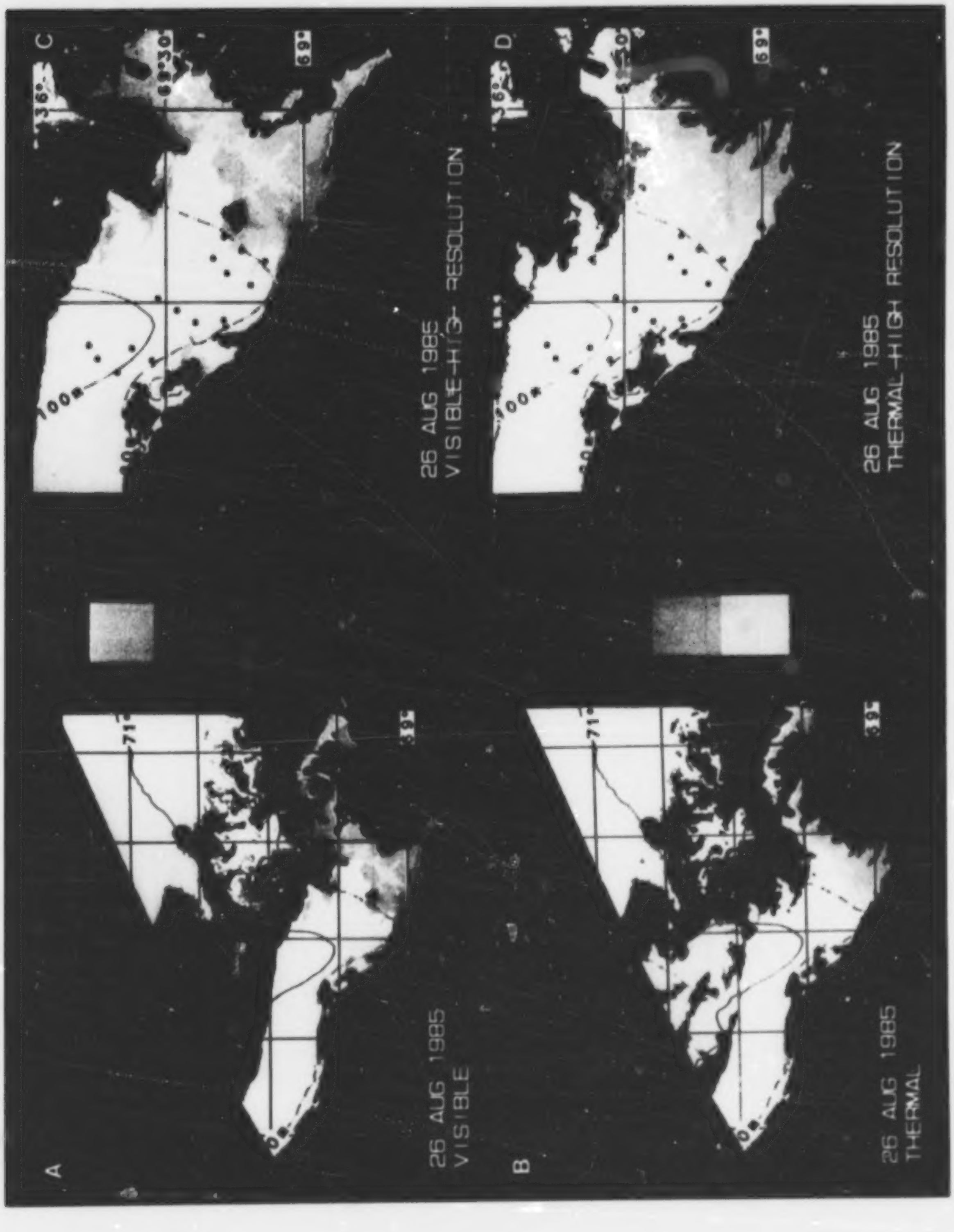

A
C
B
D
VISIBLE
THERMAL
ARCTIC
DIFFUSE
INTENSE
8
5
2.5
<1
<1
<1
<1
14
15
16
17
18
19
20
S1
S2
S3
S4
S5
S6
S7
15
16
17
18
19
20
21
5
2.5
<1
<1
<1
<1
<1
ARCTIC
DIFFUSE
INTENSE
SURFACE WATER TYPE
EST. SECCHI DEPTH (m)
PIXEL VALUES
PIXEL VALUES
EST. SECCHI DEPTH (m)
SURFACE WATER TYPE
ARCTIC
DIFFUSE
INTENSE
<0
4
5.5
8.5
11.5
14
>15
132
121
115
108
101
95
88
T1
T2
T3
T4
T5
T6
132
121
115
108
101
95
88
<0
4
5.5
8.5
11.5
14
>15
ARCTIC
DIFFUSE
INTENSE
SURFACE WATER TYPE
EST. TEMP. (°C)
PIXEL VALUES
PIXEL VALUES
EST. TEMP. (°C)
SURFACE WATER TYPE

Figure 19. Satellite imagery for 26 August 1985 (2156 GMT) derived from the AVHRR sensor on the NOAA-9 satellite. Presentation as in Figure 15.


A
26 AUG 1985
VISIBLE
B
26 AUG 1985
THERMAL
C
26 AUG 1985
VISIBLE-HIGH RESOLUTION
D
26 AUG 1985
THERMAL-HIGH RESOLUTION
100m
71°
39°
36°
69°30'
69°

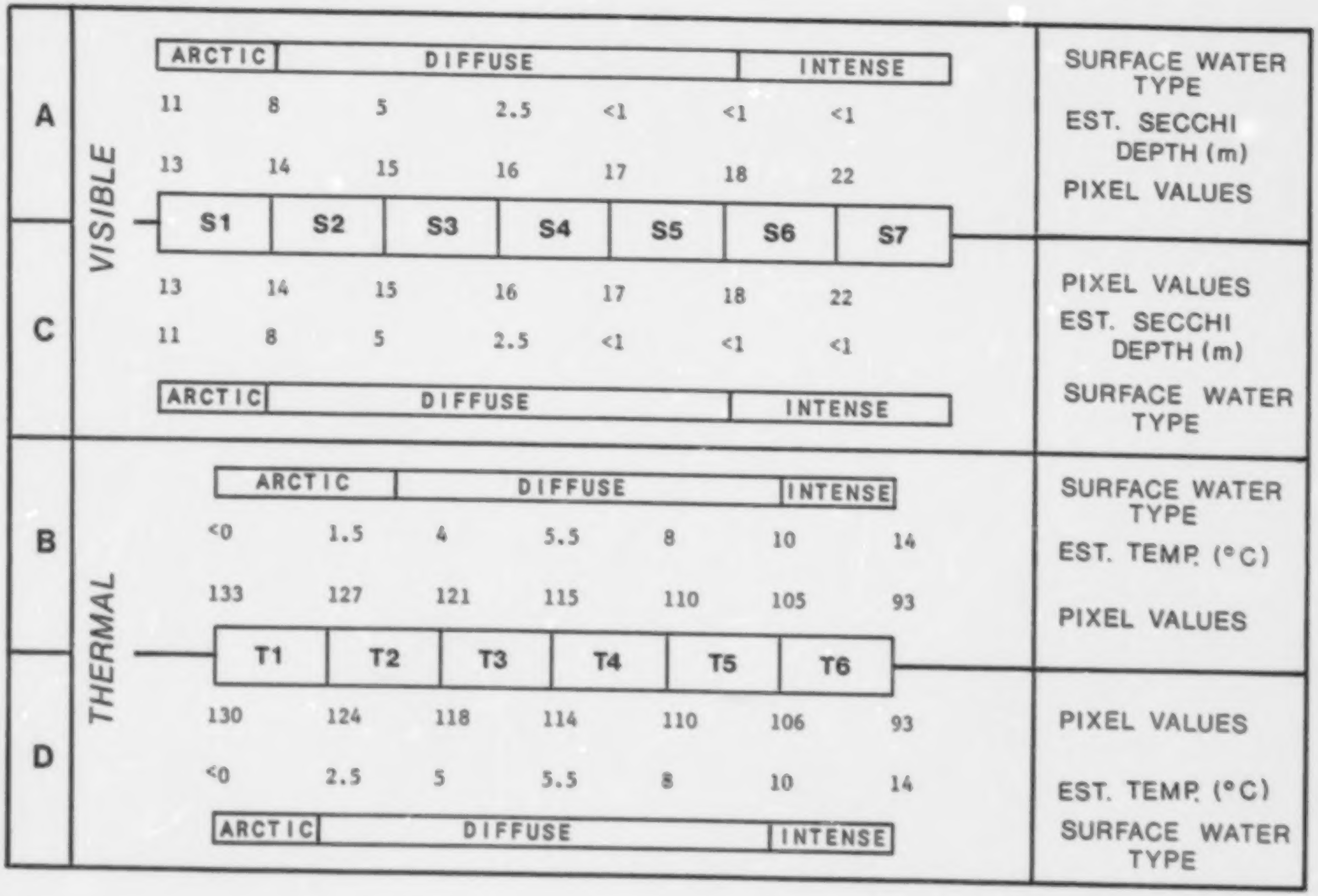
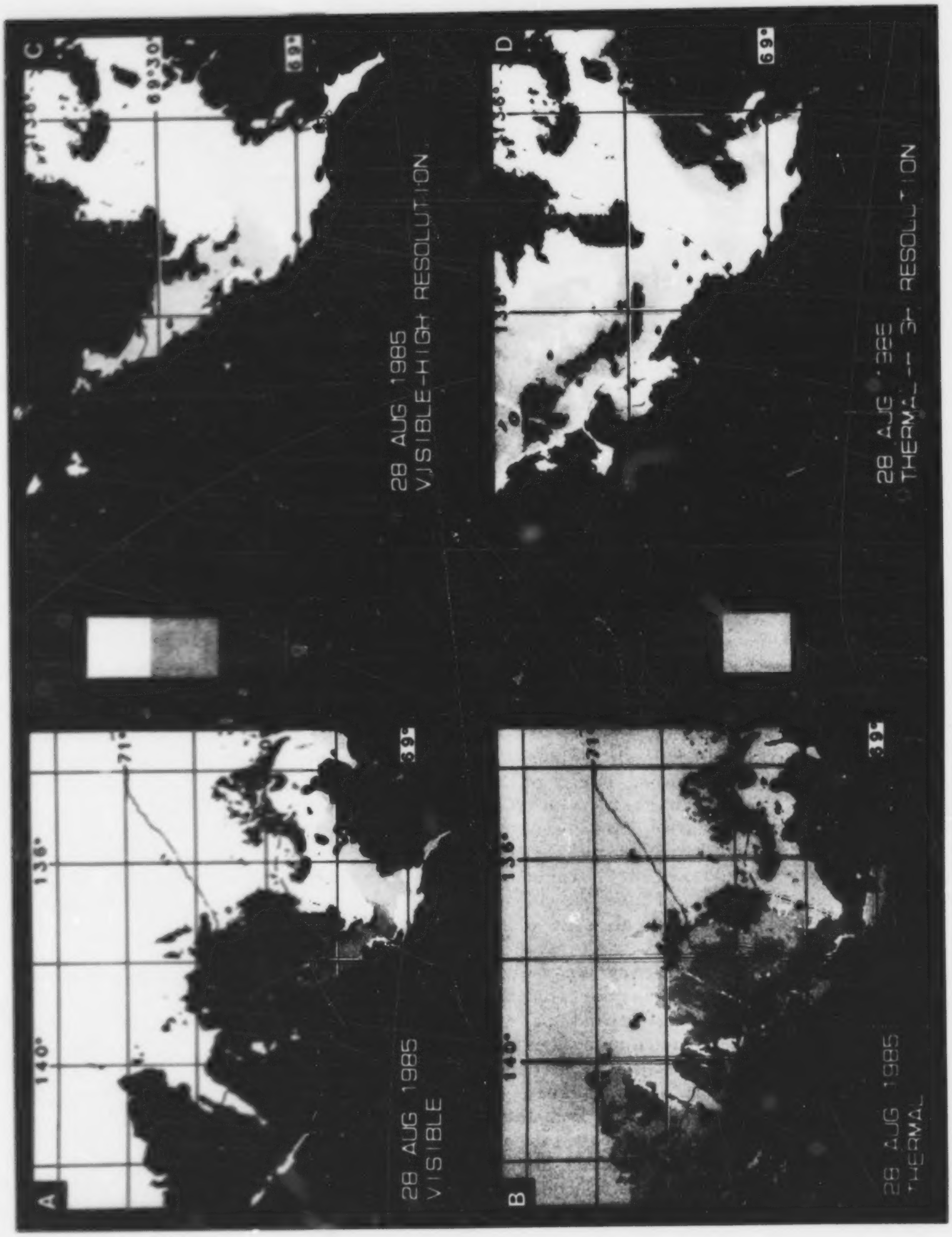

A
C
B
D
VISIBLE
THERMAL
ARCTIC
DIFFUSE
INTENSE
11 8 5 2.5 <1 <1 <1
13 14 15 16 17 18 22
S1 S2 S3 S4 S5 S6 S7
13 14 15 16 17 18 22
11 8 5 2.5 <1 <1 <1
ARCTIC
DIFFUSE
INTENSE
ARCTIC
DIFFUSE
INTENSE
<0 1.5 4 5.5 8 10 14
133 127 121 115 110 105 93
T1 T2 T3 T4 T5 T6
130 124 118 114 110 106 93
<0 2.5 5 5.5 8 10 14
ARCTIC
DIFFUSE
INTENSE
SURFACE WATER TYPE
EST. SECCHI DEPTH (m)
PIXEL VALUES
PIXEL VALUES
EST. SECCHI DEPTH (m)
SURFACE WATER TYPE
SURFACE WATER TYPE
EST. TEMP. (°C)
PIXEL VALUES
PIXEL VALUES
EST. TEMP. (°C)
SURFACE WATER TYPE

Figure 20. Satellite imagery for 28 August 1985 (2135 GMT) derived from the AVHRR sensor on the NOAA-9 satellite. Presentation as in Figure 15.


A
28 AUG 1985
VISIBLE
140°
136°
71°
69°
B
28 AUG 1985
THERMAL
140°
136°
71°
69°
C
136°
69°30'
69°
28 AUG 1985
VISIBLE-HIGH RESOLUTION
D
136°
138°
69°
28 AUG 1985
THERMAL -- HIGH RESOLUTION

approximately 50-60 km offshore near the 10 m isobath in Mackenzie Bay (Fig. 16). Temperatures of the intense plume water were 6-9°C, while the turbidity was very high (secchi depth <1 m). Prominent meanders, having scales of 10-20 km, were apparent along the northern edge of the intense plume front in Mackenzie Bay. One day later, on 21 August, the intense plume extended 5-10 km farther offshore to the vicinity of the 20 m isobath (Fig. 17). The offshore advection was likely due to the moderate-to-strong southeasterly winds experienced on 21 August. The meanders along the intense plume front appear to have increased significantly in amplitude from the previous day, with evidence that one of these meanders (near 136.5°W) had broken away from the intense plume to form an eddy 10-20 km in diameter.

By 24 August, the intense plume edge had retreated approximately 15 to 30 km shoreward (Fig. 18). The southeastward displacement of the plume front was likely due to the moderate northwesterly winds of 23 August. In addition, the plume was less clearly defined, as the area of high turbidity values (secchi depth <1 m) extended farther offshore than the area of high temperatures (5-8°C). Large meanders remained prominent along the intense plume front, particularly in the visible band. A large eddy of turbid, warmer water (temperature of 4-5°C; secchi depth <1 m), centred near 69.7°N, 137.5°W, appeared to have separated from the intense plume, perhaps originating as part of the separating meander observed on the 21 August image. In the 26 August imagery, the location of the intense plume front in northwestern Mackenzie Bay was obscured by cloud (Fig. 19). However, it was probably at least as far offshore as on 24 August. The temperature of the intense plume appears to have increased (by 5°C) to 8-13°C, over the 2-day period 24-26 August; this increase may have been caused in part from solar heating of the uppermost portion of the surface layer. In the 28 August image, the edge of the intense plume was again obscured by low cloud (Fig. 20). Temperature and turbidities in the innermost 25 km of the intense plume ranged from 10 to 14°C with secchi depths <1 m.

Yukon Coastline.--Within the Yukon coastal study area, the surface waters consisted, in large part, of a combination of diffuse plume water and arctic water. Along part of the Yukon coastline, surface water properties were at or near intense plume levels, in the form of a 15-20 km wide coastal band, extending westward to the vicinity of Shingle Point on 20 August. In later imagery (21-28 August), intense plume water was displaced offshore and replaced by water of diffuse plume or arctic water characteristics. A more detailed description for the time of each satellite image follows.

The 18 August imagery was obscured by cloud cover to the east of 138°W (Fig. 15). For the portion of the study area in which surface data were obtained (Herschel Island to Kay Point), an extension of the diffuse plume was observed extending offshore, with a northward orientation. Although slightly warmer water extended west beyond the Alaskan border, the core of the relatively warm, turbid water extending offshore was confined to a narrow band of less than 6 km width extending north from Kay Point. The estimated values of the surface water properties within the core band were temperatures of 4-5°C and secchi depths of <1 m. Along the coastline between Herschel Island and Kay Point, the surface layer was cold (<3-4°C) and of low turbidity (secchi depth >4-6 m), indicative of an arctic water influence.

On 20 August (Fig. 16), comparatively warm, turbid water, representing an extension of the intense plume, was present along the Yukon coastline. The water with near-intense plume properties occurred as a 15-20 km band extending westwards to the vicinity of King Point (138°W). However, the plume edge was not bordered by an intense front as observed farther offshore. Instead, the change from intense plume to near-arctic water characteristics occurred over a distance of 15-25 km. A diffuse plume having a width of 50 km or greater extended northwestward around Herschel Island and into the outer shelf portion of the Alaskan Beaufort Sea. The diffuse plume was characterized by temperatures of 4-6°C and secchi depths of 1-4 m. Cold, clear arctic water was present close to shore west of Herschel Island (temperature <4°C; secchi depths >4 m). Small areas (5 by 15-20 km) of arctic water were also present along the coastline near Kay Point and midway between Kay Point and Herschel Island.

One day later, on 21 August (Fig. 17), the diffuse plume appeared to be displaced offshore, likely as a result of the moderate-to-strong easterly wind experienced on that day. A nearshore band of cold, clear water having arctic water characteristics (temperature <3°C, secchi depth >7 m) was present from Herschel Island eastward to the vicinity of Shingle Point. The cold, clear water extended 20 km offshore in the Herschel Island-Kay Point embayment, narrowing to 4-8 km east of Kay Point. The offshore boundary of the latter area had more intense gradients than observed on 20 August, due to the presence of intense plume water offshore. Smaller patches of very cold water (<1°C) were again observed near and west of Kay Point and west of Shingle Point.

On the imagery from both 24 August and 26 August (Fig. 18 and 19), areas adjacent to the Yukon coastline were largely obscured by low cloud. The diffuse plume was characterized by water temperatures exceeding those of the arctic water by approximately 3°C. The temperature within the diffuse plume apparently increased from 3-5°C on 24 August to 4-8°C on the 26th. The turbidity levels within the diffuse plume were comparatively lower and, on 26 August, not significantly greater than those of the offshore arctic waters. Imagery for the portions of the coastline that were visible indicated that arctic water remained in the coastal areas on either side of Herschel Island, and that arctic water was present as a narrow band (width <5 km) between King Point and Stokes Point. The horizontal gradients on the offshore edge of this coastal band were very intense, and represented a front separating the cold arctic water near shore from the intense plume water offshore. The 28 August imagery showed that cold, clear arctic water was present along the Yukon coastline as a band 20 km wide extending from just west of Kay Point eastward nearly as far as Shingle Point. This nearshore band of arctic water had characteristics (temperature <2.5°C; secchi depth >8 m) very distinct from those farther offshore. This band was much greater in areal extent on 28 August than had been observed one week earlier (20-21 August). Farther to the west, within 40 km on either side of Herschel Island, diffuse plume water had entered the coastal areas; here surface temperatures were 2-10°C, with the warmest temperatures occurring <10 km from Herschel Island. By 28 August (Fig. 20), the diffuse plume also extended farther offshore west of Kay Point. In addition, its surface characteristics were intensified relative to those earlier. In its central core, located 30-40 km offshore, temperatures were 10-14°C, with secchi depths of 1-2.5 m. The very high temperatures observed from 138°W to 139.5°W are remarkable, as they exceed the temperatures inferred for the intense plume on 20-21 August. If real, these temperatures imply that the warm water originated during or after 24-26 August, when the intense plume was observed to increase in temperature.

The large area of arctic water along the Yukon coastline on 28 August was accompanied by very intense fronts along its northern and eastern sides. The intense fronts separate the cold coastal water from the warm, more turbid waters of the diffuse and intense plumes.

Frontal Features.--Based on the satellite imagery from 18-28 August 1985, intense frontal features were located and mapped. The fronts, as observed from satellite imagery (Fig. 21), have typical widths of 2-4.5 km with estimated changes in temperature and secchi depth of 1-4°C and <4 m, respectively. Regions of greatest frontal activity were as follows:

- the Shingle Point to King Point portion of the Yukon coastline (21, 26 and 28 August);
- off Kay Point (18, 21 and 28 August);
- off northwest Richards Island at 135°W to 136°W (20, 21, 24 and 26 August); and
- near the 20 m isobath near 69.5°N, 137°W (20, 21 and 24 August).

Intense frontal features occurred as steep gradients between cold, clear arctic water and the warmer, more turbid plume water.

Boat-based Data

The boat-based oceanographic observations provide information on the subsurface distribution of water properties, along with point measurements of surface temperature and turbidity. The CTD profile data obtained from 23 to 30 August 1985 are displayed in Figures 22 and 23. As noted in the "Materials and Methods", the salinity data are unreliable, and should only be used as a relative indication of the changes in salinity within each profile or between profiles obtained within a few hours of one another.

Most CTD profiles showed that a well-defined surface layer was present in the uppermost 5 m of the water column. The surface layer was characterized by typical surface temperatures of 3-5°C, with a maximum of 7.8°C at station 14. At stations having sufficient water depth, the temperatures below 15 m were uniformly cold (<0°C), further decreasing to near-freezing temperatures (<-1.5°C) at depths exceeding 30 m. The salinities accompanying the low temperatures were not determined during this study, but are expected to be approximately 32°/oo. Hopky et al. (1986) measured deepwater salinities of 32.3 and 32.1°/oo on 24 July and 9 September 1985, respectively, in Herschel Basin, near station 18.

At some locations, mostly near the Yukon coastline from Kay Point to Shingle Point, the surface layer was cooler (<3°C) than that farther offshore, and the thermocline was less intense. The stations lacking a prominent surface layer of warm, low-salinity water were:

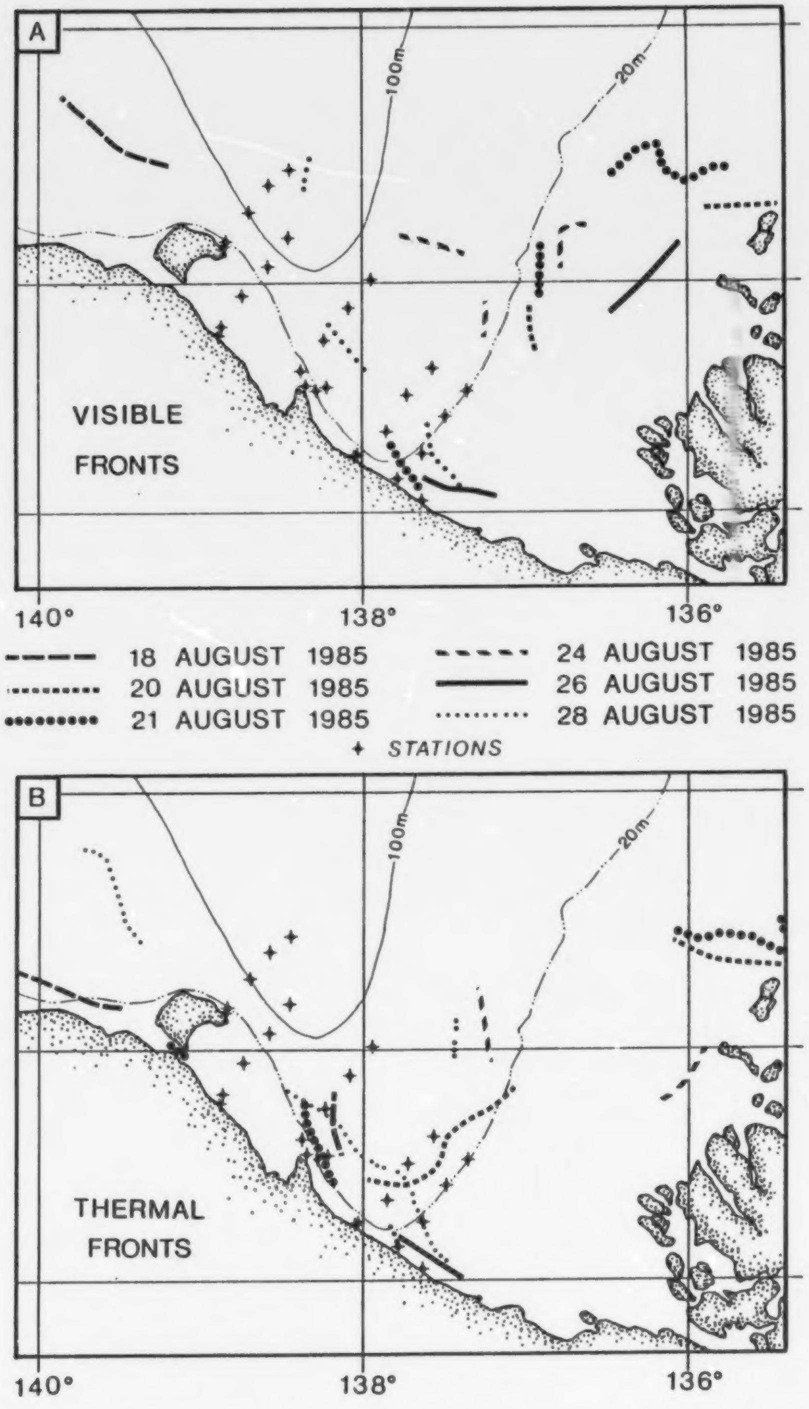

A
70°
100m
20m
69°30'
VISIBLE
FRONTS
69°
140°
138°
136°
18 AUGUST 1985
20 AUGUST 1985
21 AUGUST 1985
24 AUGUST 1985
26 AUGUST 1985
28 AUGUST 1985
✦ STATIONS
B
70°
100m
20m
69°30'
THERMAL
FRONTS
69°
140°
138°
136°

Figure 21. Locations of intense frontal feature identified from the satellite imagery of 18, 20, 21, 24, 26 and 28 August (Fig. 15-20). Note that clouds obscured major portions of the Yukon coastline in the imagery from 18, 24 and 26 August.

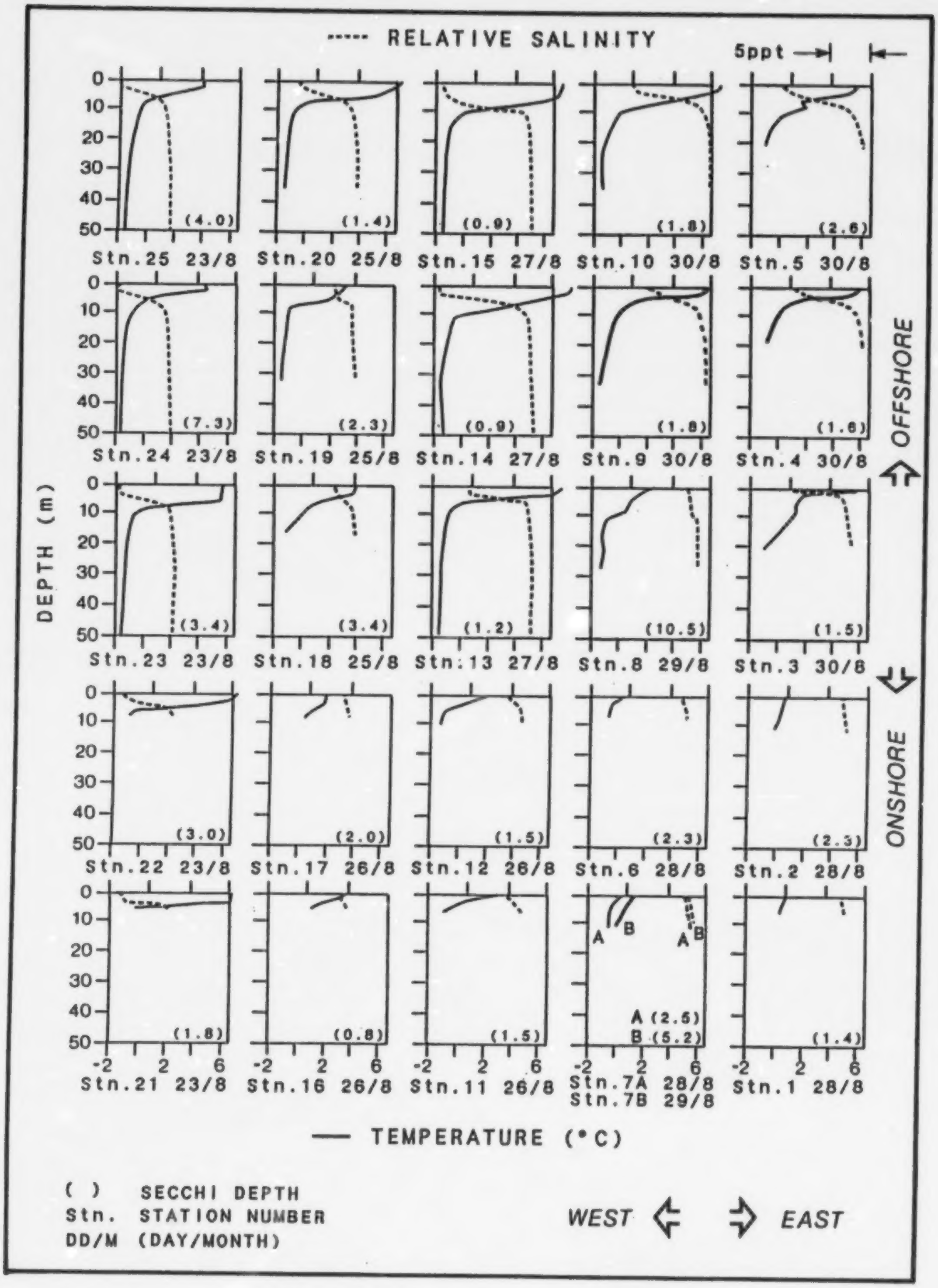


Figure 22. Vertical profiles of temperature and relative salinity obtained from the M.V. 'Sequel' at all grid-station measurement sites.

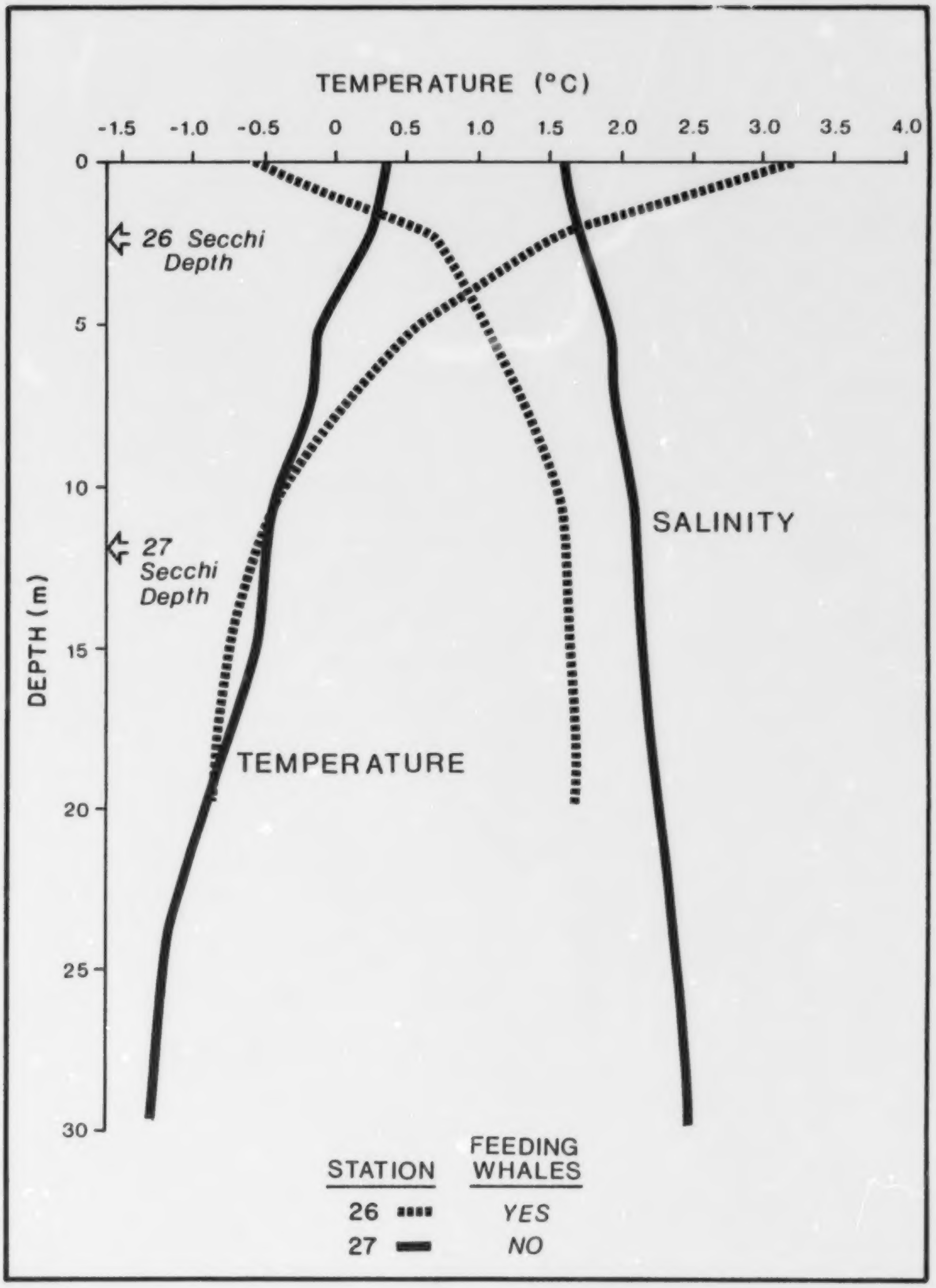


Figure 23. Vertical profiles of temperature and relative salinity at stations 26 and 27.

26 August:	Stations 16, 17, 12 and 11
28 August:	Stations 1, 2, 6 and 7A
29 August:	Station 7B, 8 and 27

With the single exception of station 8, all of the above stations were located within 5 km of the coastline, and include all measurement sites between Kay Point and Shingle Point. The lowest near-surface temperatures (<1°C) were observed on 28 August 1985 at sites located within 3 km of the coastline from King Point to Shingle Point (stations 1, 2, 6 and 7A). On the following day, low temperatures were again observed at station 7B and at station 27, located 5 km offshore near Kay Point.

To this point, we have characterized surface layer water properties into three categories (intense plume, diffuse plume and arctic water) primarily on the basis of the temperature of the surface layer. However, the turbidity measurements (secchi depths) provide evidence of further categories, particularly in the areas previously characterized as having arctic water at the surface (Fig. 24). At stations having comparatively low surface temperatures, widely varying secchi depths were observed. Stations 7B, 8 and 27 had very low turbidity levels (secchi depths >5 m) accompanied by correspondingly low surface temperatures (0.2-2.3°C). However, at some stations, generally found within 5 km of the coastline, low surface temperatures were accompanied by relatively high turbidities. At stations 11, 12, 16 and 17, temperatures of 1.9-2.9°C were accompanied by secchi depths of only 0.8-2.0 m. At nearshore stations 1, 2, 6 and 7A, surface temperatures were very low (0.2-0.8°C), but turbidities remained comparatively high as indicated by secchi depths of 1.4-2.5 m. The cold, clear surface water at stations 7B, 8 and 27 may have been upwelled due to the strong southeasterly winds during 28 August (see below). The occurrence of significant turbidity levels accompanying cold arctic water near the coastline may result from wave-driven re-suspension of sediments in the shallow coastal waters rather than advection of suspended sediments originating directly from Mackenzie River discharges.

Three CTD profiles obtained off Kay Point on 29 August (Fig. 23) were of particular interest in relation to the oceanographic conditions associated with bowhead whale feeding. At two of these stations, 26S and 26N, bowhead whales were present and presumed to be feeding. At nearby station 27, located 3.8 km farther from shore, whales were not present. At all three stations, the water column consisted of arctic water. However, near the whales, the upper portion of the water column was warmer (2.7-3.6°C) and more turbid than at the nearby station (27) where no whales were present.

The lower (deeper) portion of the surface layer, where sea-water density increases markedly with increasing depth (the pycnocline), is of potential importance as an area of accumulation of zooplankton (see next chapter). For each station, the boat-based oceanographic data were used to estimate the depth of the pycnocline (Table 4). The pycnocline was defined as the depth zone where there were strong vertical gradients in temperature and relative salinity (Figs. 22 and 23). The largest vertical gradients within the thermocline and pycnocline occurred within the uppermost 10 m of the water column. The amplitude of the vertical gradient varied greatly among measurement sites; it was largest at the offshore locations where the diffuse plume was present. At the inshore and nearshore locations, the gradients were generally weaker and more variable.

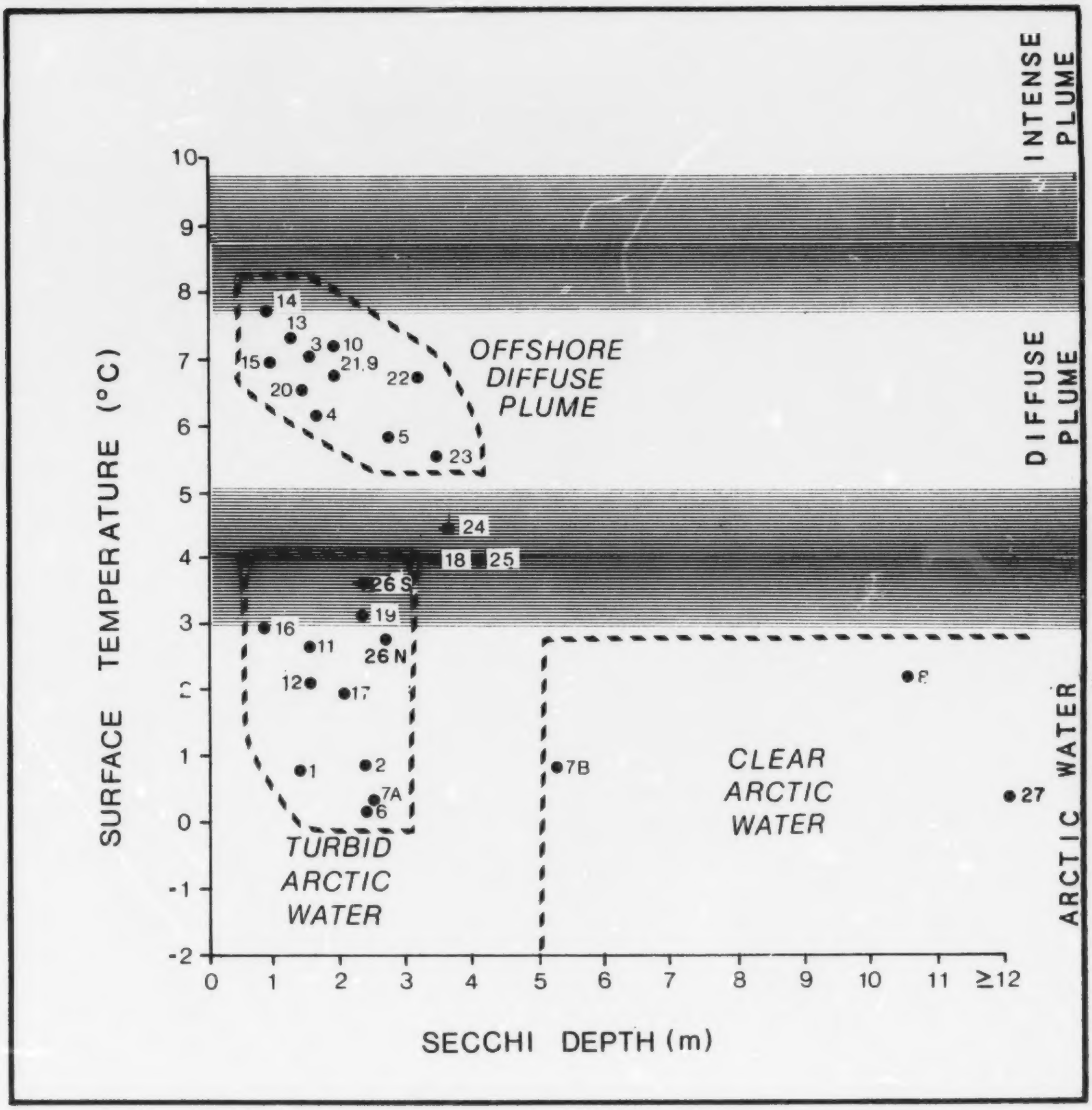


Figure 24. Plot of surface temperature versus secchi depth for all CTD stations. Numbers are stations numbers. Individual stations are grouped according to the inferred surface layer properties.

Table 4. Thermocline depths based on Hydrolab profiles of temperature and relative salinity.*

Station	Date in August	Thermocline Depths (m)		
		Top	Middle	Bottom
Transect 5				
Station 25	23	2.0	4.0	6.0
Station 24	"	2.0	3.5	5.0
Station 23	"	5.0**	6.3	7.5
Station 22	"	1.0	3.0	5.0
Station 21	"	3.0	4.0	5.0
Transect 4				
Station 20	25	2.0	4.5	7.0
Station 19	"	2.0	4.0	6.0
Station 18	"	2.0	5.5	9.0
Station 17	"	2.0	(5.5)	-
Station 16	"	1.0	-	-
Transect 3				
Station 15	27	5.0	7.5	10.0
Station 14	"	2.0	5.8	9.5
Station 13	"	2.0	3.5	5.0
Station 12	26	-	-	3.0
Station 11	"	-	-	3.0
Transect 2				
Station 10	30	2.0	5.5	9.0
Station 9	"	0.0	3.0	6.0
Station 8	29	-	-	8.0
Station 7A	28	-	-	1.0
Station 7B	29	-	-	9.0
Station 6	28	-	-	1.0
Transect 1				
Station 5	30	2.0	6.3	10.5
Station 4	"	2.0	5.3	9.0
Station 3	29	0.0	7.3	14.5
Station 2	28	-	-	8.5
Station 1	"	-	-	-
Whale Feeding Area				
Station 26N	29	0.0	4.0	8.0
Station 26S	"	0.0	4.0	8.0
Control Area				
Station 27	29	-	-	4.0

---

* The top of the thermocline generally coincided with the bottom of the diffuse plume layer. The bottom thermocline depth was taken to be the depth at which the temperature was below 0°C. The average of the top and bottom values defined the middle depth. Some profiles did not extend to the bottom of the thermocline, but the mid thermocline depth could be estimated (e.g. Station 19). Depth resolution is limited by sampling depths of 0, 2, 5, 7, 10, 15, 20, ... m.

** At station 23, the 5 m 'top' value based on temperature may be in error since the conductivity values suggest that the top of the pycnocline was at 2 m depth.

The temperature measurements, as mapped on vertical onshore to offshore cross-sections (Fig. 25), provide evidence of coastal upwelling. In three of the four cross-sections, the isotherms beneath the surface layer tilt upward toward the coastline. This temperature distribution is indicative of cold arctic water at depth being upwelled over the steep slope of the Yukon coastline. This is consistent with the satellite evidence that the area of arctic water off the Yukon coastline expanded from 20 to 28 August (Fig. 13 to 17). During this period prevailing winds blew from an easterly direction, which would be expected to drive coastal upwelling (Pond and Pickard 1978).

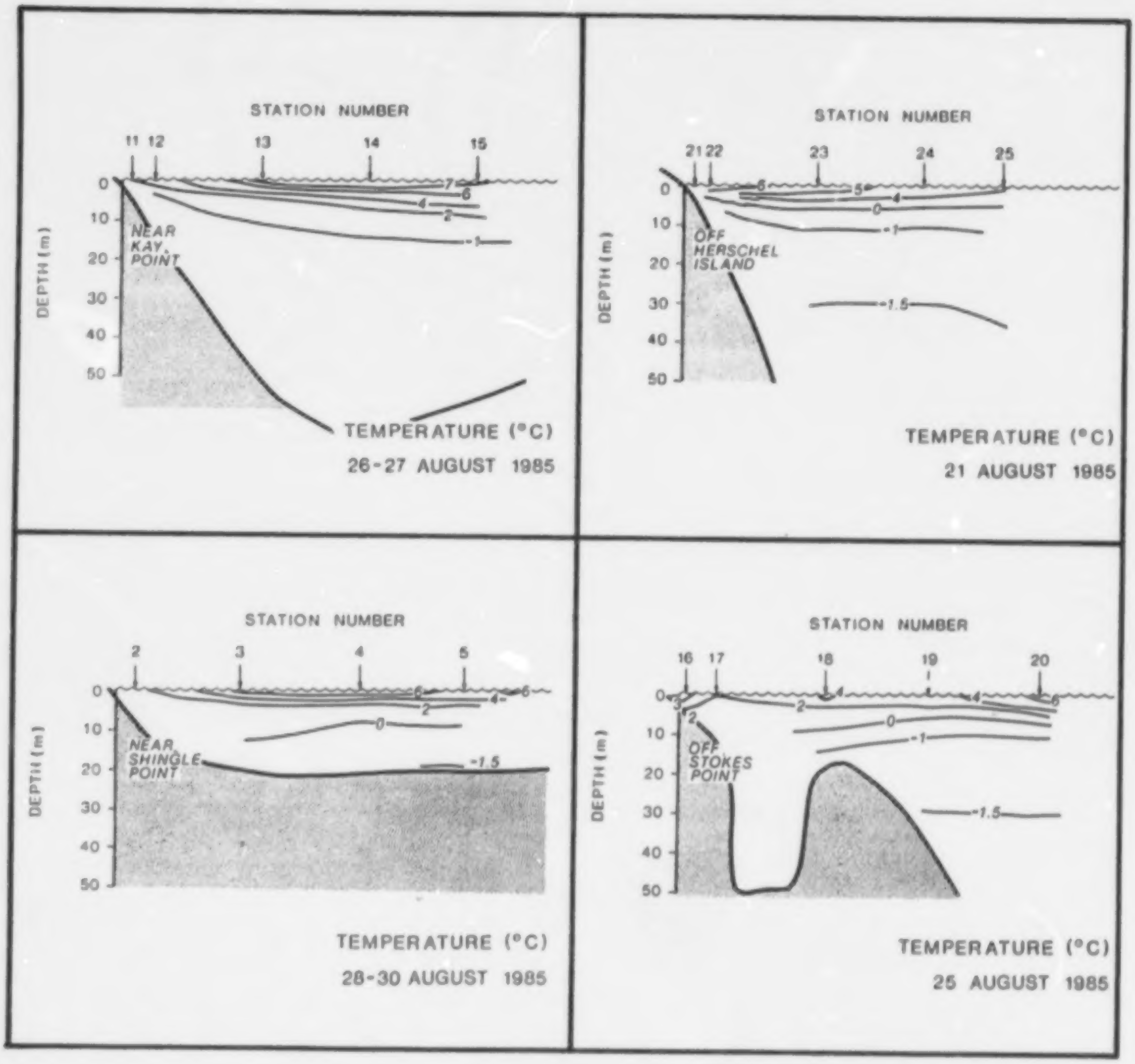


Figure 25. Vertical cross-sections of temperature along four transects oriented approximately perpendicular to the coastline. Note that the data for the Kay Point and Shingle Point cross section were obtained over 1 and 2 day periods, respectively, and could include time-dependent variations.

NET SAMPLING OF ZOOPLANKTON

Fifty-nine zooplankton tows were made during this study. Details of the composition of these samples are given in Appendices 1-4. Appendices 1 and 2 give the biomass (mg/m^3) and density (numbers/m^3) of major groups of plankton, respectively, while Appendices 3 and 4 present similar information on species of calanoid copepods.

Sampling stations were somewhat arbitrarily assigned to three categories on the basis of surface water temperature: diffuse plume waters (temperature >5°C), mixed waters (a combination of warm, diffuse plume water and cold, arctic water; temperatures from 3 to 5°C), and arctic waters (<3°C). Oblique tows, at depth, usually sampled arctic water regardless of which water mass occurred at the surface. Horizontal tows, on the other hand, mainly sampled specific water masses, although they too were variably contaminated on their descent to and ascent from the nominal sampling depth. The results from the oblique tows are used to describe, in general, the average composition of the zooplankton community in the upper portions of the water column. Results from horizontal tows provide more precise information about the zooplankton in specific water masses.

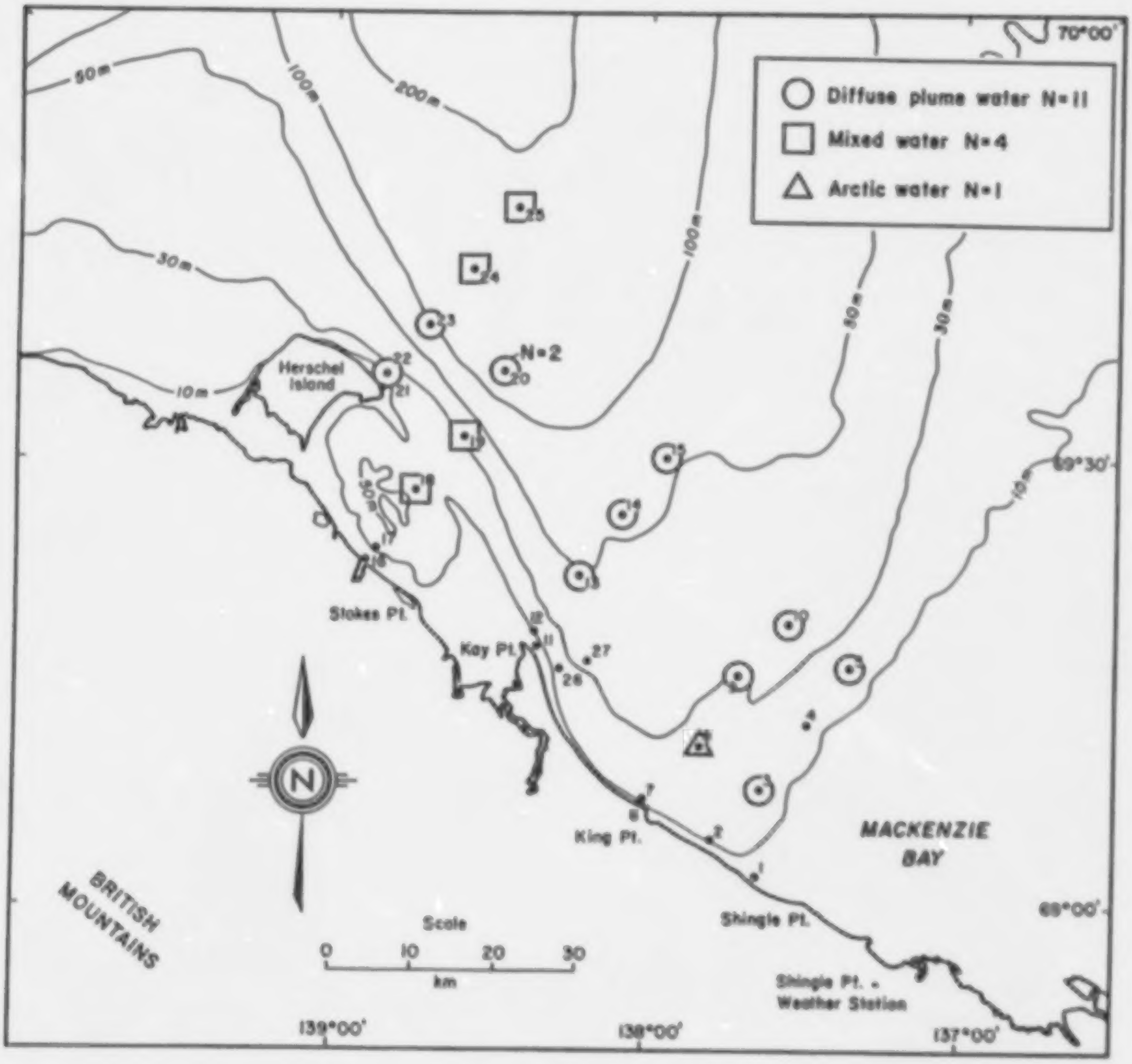
Oblique Tows

Sixteen oblique tows were made during the study (Fig. 26). In waters over 25 m deep, oblique tows sampled the upper 25 m; on average, 43% of the water column was sampled during such tows (N = 12, range 15 to 74%). In waters from 10 to 25 m deep, oblique tows sampled the upper 10 m and, on average, 59% of the water column was sampled during such tows (N = 4, range 48 to 83%). Overall, the 16 oblique tows sampled the upper 47% of the water column.

Both numerically and in terms of biomass, calanoid copepods dominated the zooplankton community (Table 5). In descending order of biomass, calanoida (86%) was followed by mysidacea (3.8%), hydrozoa (2.0%), chaetognatha (2.0%), ctenophora (1.5%), pisces (1.2%), euphausiacea (1.0%) and seven other groups with percentage contributions of <1%.

The seven groups that represented >1% of total biomass were all dominated by three or fewer taxa (Table 6). These seven groups of important zooplankton, as determined with oblique tows, were as follows:

Calanoida.--Limnocalanus macrurus formed 68% of zooplankton biomass and 79% of copepod biomass in the 16 oblique tows. We found adult males (50.8 mg/m^3), adult females (92.8), and copepodite stages V (0.4) and IV (<0.01). The overall average biomass of L. macrurus was 144.0 mg/m^3. In terms of biomass, Calanus hyperboreus was the second most important copepod. We found adult females (8.9 mg/m^3), and copepodite stages V (2.0), IV (3.5), III (0.9) and II (<0.01) in the samples. The overall biomass was 15.4 mg/m^3. Calanus glacialis ranked third in importance in the oblique tows; we found adult males (0.1 mg/m^3), adult females (5.8), and copepodite stages V (3.0), IV (2.7), III (0.8) and II (0.1). The overall biomass was 12.6 mg/m^3. Other calanoids present included Pseudocalanus minutus, Derjuginia tolli, Euchaeta glacialis, Metridia longa, Acartia longiremis, and Centropages hamata.


Diffuse plume water N=11
Mixed water N=4
Arctic water N=1
70°00'
69°30'
69°00'
139°00'
138°00'
137°00'
50m
100m
200m
30m
10m
N=2
Herschel Island
Stokes Pt.
Kay Pt.
King Pt.
Shingle Pt.
Shingle Pt. - Weather Station
MACKENZIE BAY
BRITISH MOUNTAINS
N
Scale
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20
30
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Figure 26. Locations of oblique tows at sampling stations with differing surface water characteristics.

Table 5. Biomass and density of major groups of zooplankton taken in 16 oblique tows off the Yukon coast, August 1985.

Taxon	Biomass (mg/m^3)	Percent	Density ($no./m^3$)	Percent
Hydrozoa	4.12	1.96	1.15	.285
Ctenophora	3.06	1.45	.07	.017
Pteropoda	.76	.36	.64	.159
Chaetognatha	4.27	2.03	.47	.117
Larvaceans	<0.01	<0.01	<0.01	<0.001
Pisces	2.46	1.17	.05	.012
Mysidacea	8.03	3.81	.75	.186
Euphausiacea	2.17	1.03	.04	.010
Decapoda	1.01	.48	.09	.022
Calanoida	181.21	86.02	399.89	99.135
Hyperiidae	1.97	.94	.16	.040
Gammaridea	.90	.43	.05	.012
Echinoderms	<0.01	<0.01	.02	.005
Isopoda	.01	<0.01	<0.01	<0.001
All Zooplankton	210.65	100.00	403.38	100.000

Table 6. Dominant taxa in zooplankton groups representing greater than one percent of total zooplankton biomass in 16 oblique tows.

Group	Number of taxa	Number of genera*	Dominant taxa	Mean mg/m^3	% of group total
Calanoida	10	8	*Limnocalanus macrurus*	143.978	94.9
			Calanus hyperboreus	15.371	
			Calanus glacialis	12.562	
Mysidacea	3	1	*Mysis litoralis*	7.765	100.0
			Mysis spp.	.248	
			Mysis oculata	.019	
Chaetognatha	4	2	*Sagitta elegans*	3.192	98.8
			Eukrohnia hamata	.668	
			Sagitta spp.	.356	
Hydrozoa	9	7	*Aglantha digitale*	3.278	97.0
			Halitholus cirratus	.476	
			Hydrozoa spp.	.243	
Ctenophora	4	3	*Beroe cucumis*	1.150	97.0
			Mertensia ovum	.910	
			Beroe spp.	.908	
Pisces	4	(3)*	Gadidae larvae	2.116	96.8
			Liparidae larvae	.161	
			Cottidae larvae	.101	
Euphausiacea	2	1	*Thysanoessa raschii*	1.837	100.0
			Thysanoessa inermis	.337	

* For pisces, value is number of families.

Mysidacea.--We found three taxa of mysids in the samples from oblique tows. *Mysis litoralis* comprised 3.7% of zooplankton biomass and 97% of mysid biomass. *Mysis oculata* was the other mysid species identified (0.2%). The overall biomass of mysids was 8.0 mg/m^3.

Chaetognatha.--We found two species of chaetognaths in our oblique tows. *Sagitta elegans* formed 1.5% of zooplankton biomass and 75% of chaetognath biomass. *Eukrohnia hamata* formed 16% of chaetognath biomass. The overall biomass of chaetognaths was 4.3 mg/m^3.

Hydrozoa.--We found nine taxa of hydrozoans in our oblique tows. *Aglantha digitale* was the dominant species, forming 1.6% of zooplankton biomass and 80% of hydrozoan biomass. *Halitholus cirratus* was the second dominant species (12% of hydrozoan biomass). We identified five other species of hydrozoans: *Eumedusa birulai*, *Sarsia tubulosa*, *Halitholus pauper*, *Euphysa flamea* and *Aeginopsis laurenti*. The overall biomass of hydrozoans was 4.1 mg/m^3.

Ctenophora.--We recorded three species of ctenophores in the oblique tows. *Beroe cucumis* formed 0.5% of zooplankton biomass and 38% of ctenophore biomass. *Mertensia ovum* formed an additional 30% of ctenophore biomass. Overall ctenophore biomass was 3.1 mg/m^3.

Pisces.--We recorded young-of-the-year fish from four families in our 16 oblique tows. Gadidae formed 1% of zooplankton biomass and 86% of fish biomass. We also recorded liparidae (7% of fish biomass), cottidae (4%) and stichaeidae (3%). The overall biomass of fish was 2.5 mg/m^3.

Euphausiacea.--We recorded two species of euphausiids in the oblique tows. *Thysanoessa raschii* formed 0.9% of zooplankton biomass and 85% of euphausiid biomass. *T. inermis* formed the remaining 15% of euphausiid biomass. The overall biomass of euphausiids was 2.2 mg/m^3.

Comparison of Important Groups and Species of Zooplankton in Areas with Different Surface Water Characteristics.-- As noted above, sampling stations were assigned to three categories on the basis of surface water characteristics. The three categories, distinguished on the basis of water temperature at the surface, were called diffuse plume water, mixed water, and arctic water. The biomasses of important groups and species of zooplankton in two of these surface-water categories were compared but no significant differences were found (Table 7).

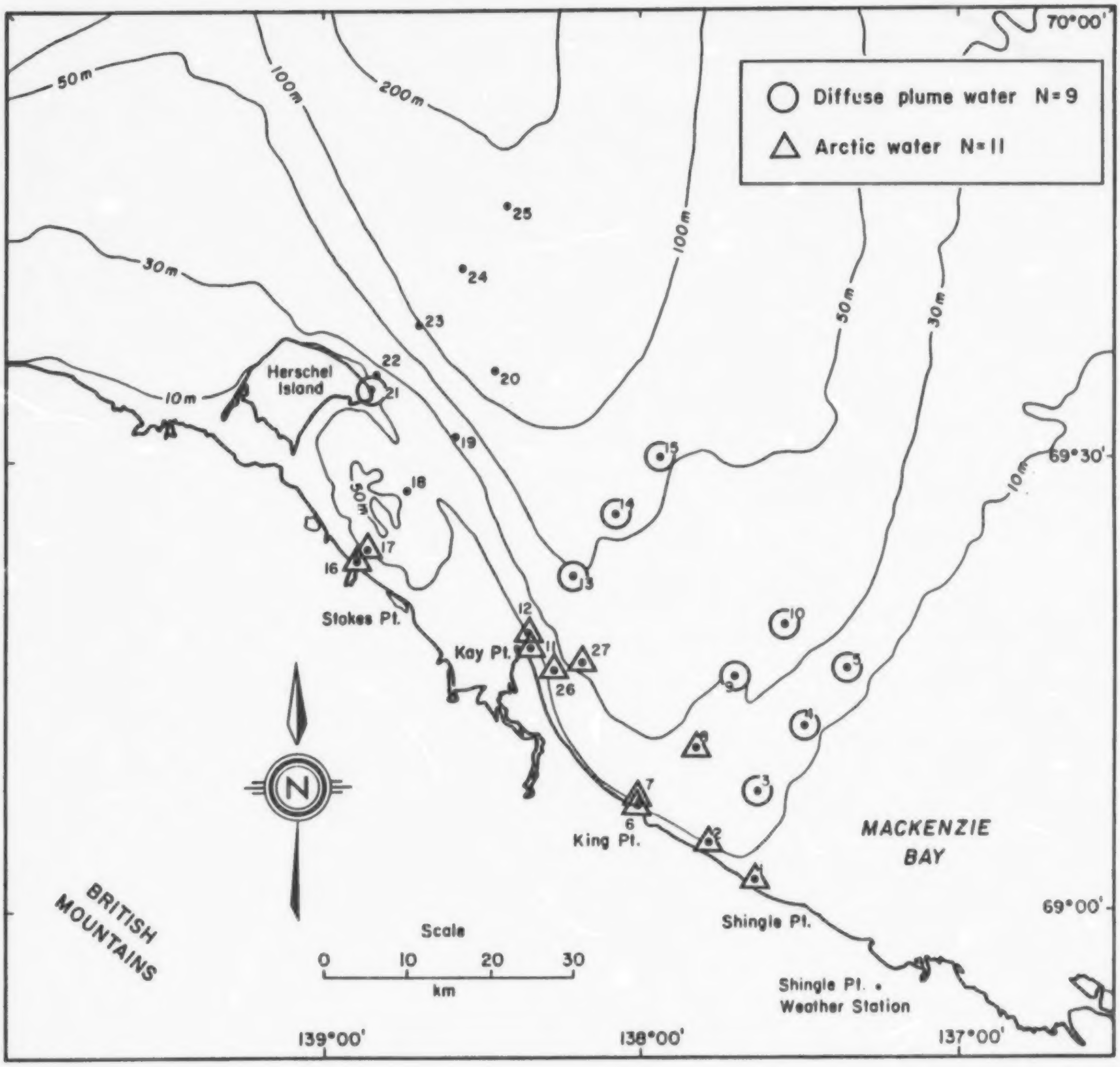
Surface Horizontal Tows

We made 20 'surface' horizontal tows (depth of about 1 m). Eleven of these tows were made in diffuse plume water (stations with water temperatures >5°C) and nine were made in arctic water (surface temperature <3°C) (Fig. 27). None was made in mixed water.

Diffuse Plume Tows.--The mean biomass of all zooplankton in surface tows made in diffuse plume waters was 59.2 mg/m^3 (SD = 147.4, N = 9, Tables 8 and 9). There were only three important taxa in these tows (important taxa are those zooplankton groups or copepod taxa forming >1% of the biomass of all zooplankton): *Limnocalanus macrurus* (94%), mysidacea (2.5%) and calanoid

Table 7. Biomass (mg/m^3) of major groups and species of zooplankton in 16 oblique tows at stations with different surface water characteristics.

Group/species	Diffuse plume water N = 11		Mixed water N = 4		Arctic water N = 1		Diffuse vs. mixed comparison	
	Mean	SD	Mean	SD	Mean	SD	U	P
Calanoida	171.09	214.56	222.42	352.02	127.54	-	14	>0.1
Limnocalanus macrurus	134.53	212.29	186.46	349.13	78.03	-	16	>0.1
Calanus hyperboreus	14.41	12.80	15.61	12.05	24.98	-	20	>0.1
Calanus glacialis	10.43	6.14	16.04	10.54	22.16	-	16	>0.1
Mysidacea	10.80	18.65	2.12	2.68	1.22	-	19	>0.1
Chaetognatha	4.17	3.58	5.05	3.17	2.22	-	17	>0.1
Hydrozoa	3.64	3.87	4.18	3.51	9.16	-	19	>0.1
Ctenophora	2.43	5.74	3.04	4.58	10.11	-	14	>0.1
Pisces	3.15	4.28	1.17	1.91	0.00	-	13	>0.1
Euphausiacea	1.93	3.59	.61	.93	11.13	-	18	>0.1
All zooplankton	202.42	226.71	243.43	354.45	170.00	-	15	>0.1



Diffuse plume water N=9
Arctic water N=11
70°00'
69°30'
69°00'
139°00'
138°00'
137°00'
50m
100m
200m
100m
30m
50m
30m
10m
10m
30m
Herschel Island
Stokes Pt.
Kay Pt.
King Pt.
Shingle Pt.
Shingle Pt. Weather Station
MACKENZIE BAY
BRITISH MOUNTAINS
N
Scale
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Figure 27. Locations of near-surface (1 m) horizontal tows.

Table 8. Mean biomass of groups of zooplankton in surface horizontal tows made in diffuse plume and arctic waters.

Taxon	Diffuse plume N = 11		Arctic water N = 9	
	Biomass (mg/m^3)	Percent	Biomass (mg/m^3)	Percent
Hydrozoa	.07	.1	3.44	.4
Ctenophora	.11	.2	1.18	.1
Pteropoda	.02	<0.1	.73	.1
Chaetognatha	.04	.1	3.83	.4
Larvaceans	0.00	0.0	.01	<0.1
Pisces	.28	.5	1.18	.1
Mysidacea	1.46	2.5	.68	.1
Decapoda	.03	<0.1	.02	<0.1
Calanoida	56.96	96.2	876.37	98.6
Hyperiidae	<0.01	<0.1	.13	<0.1
Gammaridea	.10	<0.1	.68	<0.1
Isopoda	0.00	0.0	.01	<0.1
All zooplankton	59.19	100.0	888.80	100.0

Table 9. Mean biomass of copepod taxa in surface horizontal tows made in diffuse plume and arctic waters.

Taxon	Diffuse plume N = 9		Arctic water N = 16	
	Biomass (mg/m^3)	Percent	Biomass (mg/m^3)	Percent
Calanus hyperboreus	.09	.1	18.96	2.1
Calanus glacialis	.18	.3	.96	.1
Pseudocalanus minutus	.20	.30	1.91	.2
Derjuginia tolli	<0.01	<0.1	.19	<0.1
Euchaeta glacialis	0.00	0.0	<0.01	<0.1
Metridia longa	<0.01	<0.1	<0.01	<0.1
Limnocalanus macrurus	55.62	94.0	831.02	93.5
Chiridius obtusifrons	0.00	0.00	<0.01	<0.1
Centropages hamata	<0.01	<0.1	0.00	0.00
unidentified calanoid	<0.01	<0.1	0.00	0.00
calanoid skeletons	.87	1.50	23.33	2.6
All zooplankton	59.19	100.0	888.80	100.0

skeletons (1.5%). We compared the biomasses of all zooplankton between stations in the eastern and western portions of the study area (transects 1 and 2 vs. 3 to 5, respectively) and found no differences (U = 6, P>0.1). We also found no difference in the biomasses of all zooplankton between inshore and offshore stations (innermost three stations on each transect line vs. outermost two stations) (U = 5, P>0.1).

Arctic Water Tows.--The mean biomass of all zooplankton in surface tows made in arctic waters was 888.8 mg/m^3 (SD = 708.2, N = 11, Tables 8 and 9), or about 15 times that found in diffuse plume waters. There were three important taxa: *Limnocalanus macrurus* (94%), calanoid skeletons (2.6%) and *Calanus hyperboreus* (2.1%). We compared the biomasses of all zooplankton on eastern vs. western transects and found no differences (U = 5, P>0.1). We also compared the biomasses of all zooplankton at those stations closest to shore (generally over waters about 5 m deep) with those at the next station offshore (generally over waters 10 m deep) and again found no differences (Wilcoxon T = 17, P>0.1). As described above, stations with arctic water at the surface had varying levels of suspended sediments as reflected by secchi depths. Stations were divided on the basis of secchi depth into two groups: clear (secchi depths >5 m) and turbid (secchi depths from 0.8 to 2 m). There were no differences in the biomasses of all zooplankton between clear and turbid arctic water (U = 6, P>0.1).

Comparison of Near-surface Zooplankton in Diffuse Plume and Arctic Waters.--We compared the biomasses of all zooplankton and important taxa of zooplankton between stations with surface tows in diffuse plume waters (N = 9) and arctic waters (N = 11) (Table 10). There were significantly greater biomasses of *Limnocalanus macrurus* in the surface tows made in arctic waters than in those made in diffuse plume waters (see Table 9 for biomasses). The biomass in arctic waters was on average 15 times that in diffuse plume waters (Table 9). The significant difference in the amounts of *L. macrurus* in the two water masses undoubtedly accounted for similar significant differences in calanoid copepods as a group and all zooplankton (Table 8, Fig. 28). *L. macrurus* dominated surface zooplankton tows (diffuse plume water: 98% of copepod biomass, 94% of zooplankton biomass; arctic water: 95% of copepod biomass, 94% of zooplankton biomass).

Horizontal Tows at Depth

We made 23 horizontal tows at varying depths in diffuse plume (N = 5) and arctic (N = 18) waters (Fig. 29). Twenty-one of the tows were made at locations and depths from which the echosounder received dense echo. This echo presumably represented concentrations of potential food items for bowhead whales. The other two tows were made at depths where no apparent concentrations of food were detectable from the echogram. At stations with diffuse plume water at the surface, zooplankton tows made below the mid thermocline depth were, in fact, sampling arctic water. The analyses presented below have been organized to reflect this fact.

Zooplankton biomasses were greater in potential prey patches in arctic water (mean biomass of 576.5 mg/m^3) than in similar patches in diffuse plume water (71.1). Copepods, and especially *Limnocalanus macrurus* dominated the zooplankton from both water masses (Tables 11 and 12).

Table 10. Comparisons of the biomass of important taxa of zooplankton between diffuse plume waters and arctic waters.

Taxon	Mann-Whitney U	P
All zooplankton	12	<0.02
Calanoida	11	<0.02
Limnocalanus macrurus	12	<0.02
Calanus hyperboreus	25.5	>0.5
calanoid skeletons	29.5	>0.1
Mysidacea	38.5	>0.1

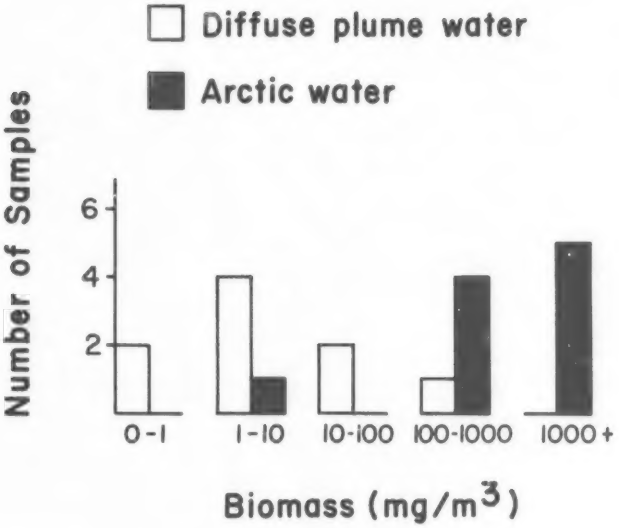
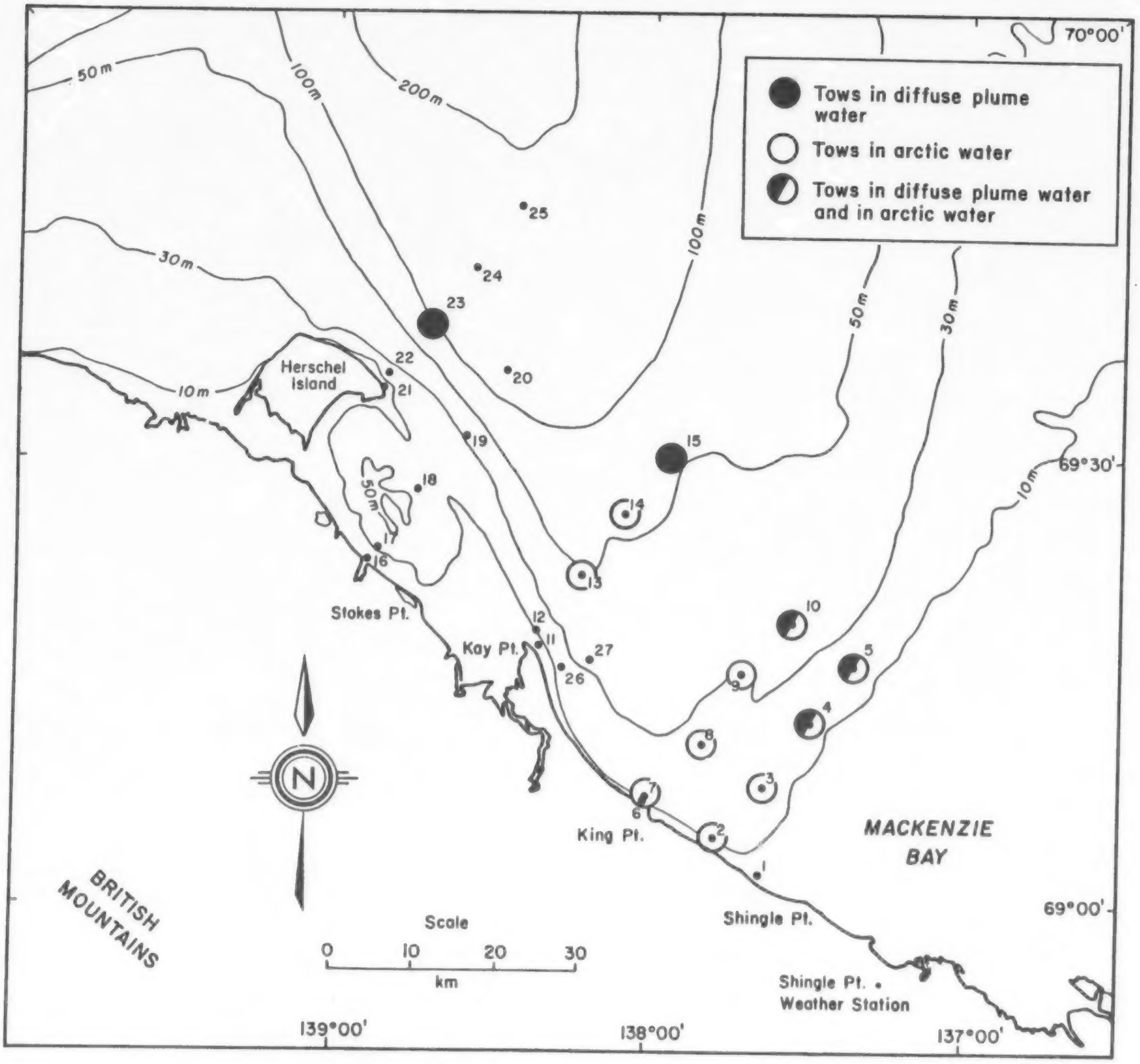


Figure 28. Distribution of zooplankton biomasses in horizontal surface tows.


70°00'
● Tows in diffuse plume water
○ Tows in arctic water
◐ Tows in diffuse plume water and in arctic water
50 m
100 m
200 m
30 m
10 m
100 m
50 m
30 m
10 m
50 m
Herschel Island
Stokes Pt.
Kay Pt.
King Pt.
Shingle Pt.
Shingle Pt. Weather Station
MACKENZIE BAY
BRITISH MOUNTAINS
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69°00'
139°00'
138°00'
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Figure 29. Locations of horizontal tows at depth made in apparent zooplankton patches as demonstrated by bands of dense echo from Ross 200 kHz sounder.

Table 11. Mean biomass of groups of zooplankton in horizontal tows through suspected prey patches in diffuse plume and arctic waters.

Taxon	Diffuse plume N = 5 Biomass (mg/m^3)	Diffuse plume N = 5 Percent	Arctic water N = 16 Biomass (mg/m^3)	Arctic water N = 16 Percent
Hydrozoa	.21	.3	6.02	1.0
Ctenophora	.71	1.0	2.04	.4
Pteropoda	.01	<0.1	1.34	.2
Chaetognatha	.10	<0.1	3.77	.7
Larvaceans	0.00	0.0	<0.01	<0.1
Pisces	10.67	15.0	6.54	1.1
Ostracoda	0.00	0.0	.16	<0.1
Mysidacea	.82	1.1	10.48	1.8
Euphausiacea	.04	<0.1	5.78	1.0
Decapoda	.21	<0.1	1.18	.2
Calanoida	54.09	76.1	532.06	92.3
Hyperiidae	3.32	4.7	4.67	.8
Gammaridea	.49	.7	1.25	.2
Hydroids	0.00	0.0	.01	<0.1
All zooplankton	71.11	100.0	576.49	100.0

Table 12. Mean biomass of copepods in horizontal tows through suspected prey patches in diffuse plume and arctic waters.

Taxon	Diffuse plume N = 5		Arctic water N = 16	
	Biomass (mg/m^3)	Percent	Biomass (mg/m^3)	Percent
Calanus hyperboreus	14.59	20.5	23.13	4.0
Calanus glacialis	6.58	9.2	14.67	2.5
Pseudocalanus minutus	<0.01	<0.1	.83	.1
Derjuginia tolli	0.00	0.0	.11	<0.1
Euchaeta glacialis	3.15	4.4	1.52	.3
Metridia longa	0.00	0.0	.67	<0.1
Acartia spp.	<0.01	<0.1	0.00	0.0
Limnocalanus macrurus	29.76	44.1	457.71	79.4
calanoid skeletons	.02	<0.1	33.41	5.8
All zooplankton	71.11	100.0	576.49	100.0

We compared the biomasses of important taxa in potential prey patches in diffuse plume and arctic waters (Table 13, Fig. 30). For each of the five taxa where significant differences were found (hydrozoa, mysidacea, euphausiacea, Calanus hyperboreus, Limnocalanus macrurus), higher biomasses occurred in arctic waters.

We found no differences in biomasses of all zooplankton between horizontal tows made at the surface vs. tows made at depth in either diffuse plume ($U = 11$, $P>0.1$) or arctic ($U = 57$, $P>0.1$) waters. When horizontal tows at the surface and at depth were combined, zooplankton biomasses were greater in arctic waters (704 mg/m^3) than in diffuse plume waters (63 mg/m^3; $z = 4.07$, $P<0.001$).

Sampling in Apparent Whale Feeding Areas

Zooplankton were sampled at four locations where bowhead whales were apparently feeding. Echograms were used to detect potential prey patches at depth. The transducer was towed approximately 1 m below the surface. Because of this, along with turbulence in the surface waters, no meaningful hydroacoustic results were obtained from the upper 2 m of water. Surface horizontal tows (made at a depth of 1 m) were employed to detect any near-surface aggregations of zooplankton.

Station 14.--On 27 August, a whale surfaced about 80 m from the boat as we arrived at this station, 'fluked-out' and dived. Two distinct bands of echo were visible on the echogram (Fig. 31). One of these bands, at 6-11 m, was sampled by a horizontal tow at a depth of 7.9 m. The deeper band (39-46 m) was too deep for our sampling gear. A thin layer of diffuse plume water, 2 m in depth, was present at the surface at this station (Table 4, Fig. 22). A surface horizontal tow revealed that this water contained few zooplankton (1.2 mg/m^3). The distinct band at 7.9 m depth was below the middle of the thermocline and apparently in arctic water (Table 4). A horizontal tow through this band revealed a biomass of 1098 mg/m^3, mainly Limnocalanus (Table 14). A horizontal tow through at a depth with little echo (21.1 m) revealed small amounts of zooplankton (126 mg/m^3).

Station 2.--On 28 August, two whales surfaced <60 m from the boat while we were working at this station. One of the whales respired a few times, 'fluked-out' and dived, while the other swam along at the surface for about 200 m before sinking below the surface (it did not 'fluke-out', a posture typically displayed at the start of a deep dive). The behaviour of the two whales suggested that they were feeding below the surface and near the surface, respectively. Arctic water was present at the surface and water temperature was 0°C at 8.5 m (Table 4). A surface tow gave the second highest biomass of any tow made during the study and the highest biomass of any surface tow (Fig. 31, 2142 mg/m^3). A broad band between the bottom (11 m) and 4 m was sampled at 7.7 m; it contained a biomass of 1399 mg/m^3. Most biomass at both depths was contributed by Limnocalanus (Table 14).

Station 3.--On 29 August, several whales were seen surfacing and diving within 1000 m of the boat while we were working at this station. Two whales, within 500 m of the boat, were below the surface for several minutes at a time, and surfaced and 'fluked-out' repeatedly in the same general area, suggesting that they may have been feeding in the water column. Station 3

Table 13. Comparisons of the biomass of important taxa of zooplankton in suspected prey patches in diffuse plume (N = 5 tows) and arctic (N = 16) waters.

Taxon	Mann-Whitney U	P
All zooplankton	9	<0.02
Hydrozoa	3	<0.002
Pisces	34.5	>0.1
Mysidacea	6	<0.02
Euphausiacea	6	<0.02
Calanoida	10	<0.02
Calanus hyperboreus	15	.05
Calanus glacialis	21	>0.1
Limnocalanus macrurus	9	<0.02
Euchaeta glacialis	38	>0.1
calanoid skeletons	32.5	>0.1
Hyperiidae	16	<0.1

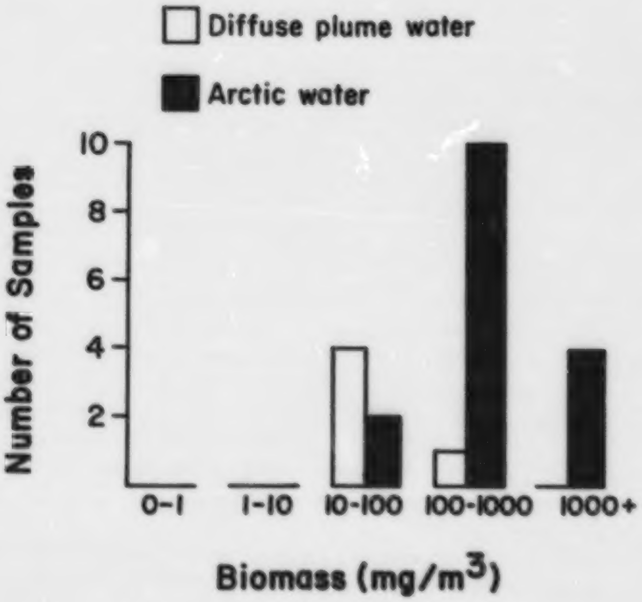


Figure 30. Distribution of zooplankton biomasses in horizontal tows through potential prey patches in diffuse plume and arctic waters.

Table 14. Composition of zooplankton samples collected in the vicinity of apparently feeding bowhead whales at three locations.

Location	Sample depth (m)	Whales feeding?	Zooplankton biomass mg/m^3	Taxa comprising greater than 1% of biomass	%
Station 14	1	No	1.3	Copepoda	81.4
				Limnocalanus macrurus	55.4
				Calanus hyperboreus	21.8
				calanoid skeletons	2.0
				Calanus glacialis	1.6
				unidentified zooplankton	18.6
	7.9	Yes	1097.7	Copepoda	94.6
				Limnocalanus macrurus	82.7
				calanoid skeletons	7.3
				Calanus glacialis	2.8
				Calanus hyperboreus	1.8
				Mysidacea	1.9
				Pisces	1.9
				Decapoda	1.9
	21	?	125.9	Copepoda	79.6
				Limnocalanus macrurus	49.9
				Calanus hyperboreus	12.0
				Calanus glacialis	10.8
				Pseudocalanus minutus	4.0
				Euchaeta glacialis	2.4
				Euphausiacea	4.8
				Pisces	3.7
				Hydrozoa	3.2
				Chaetognatha	3.2
				Hyperiidae	1.6
				Mysidacea	1.3
Station 2	1	Yes	2141.9	Copepoda	98.5
				Limnocalanus macrurus	97.3
	7.7	Yes	1399.2	Copepoda	95.1
				Limnocalanus macrurus	89.6
				calanoid skeletons	2.3
				Calanus hyperboreus	2.3
				Chaetognatha	1.8
				Hydrozoa	1.2
				Mysidacea	1.2
Station 3	1	?	448.6	Copepoda	99.1
				Limnocalanus macrurus	97.6
				calanoid skeletons	1.5
	8.6	Yes	1203.0	Copepoda	97.1
				Limnocalanus macrurus	89.9
				calanoid skeletons	6.2
				Mysidacea	1.7

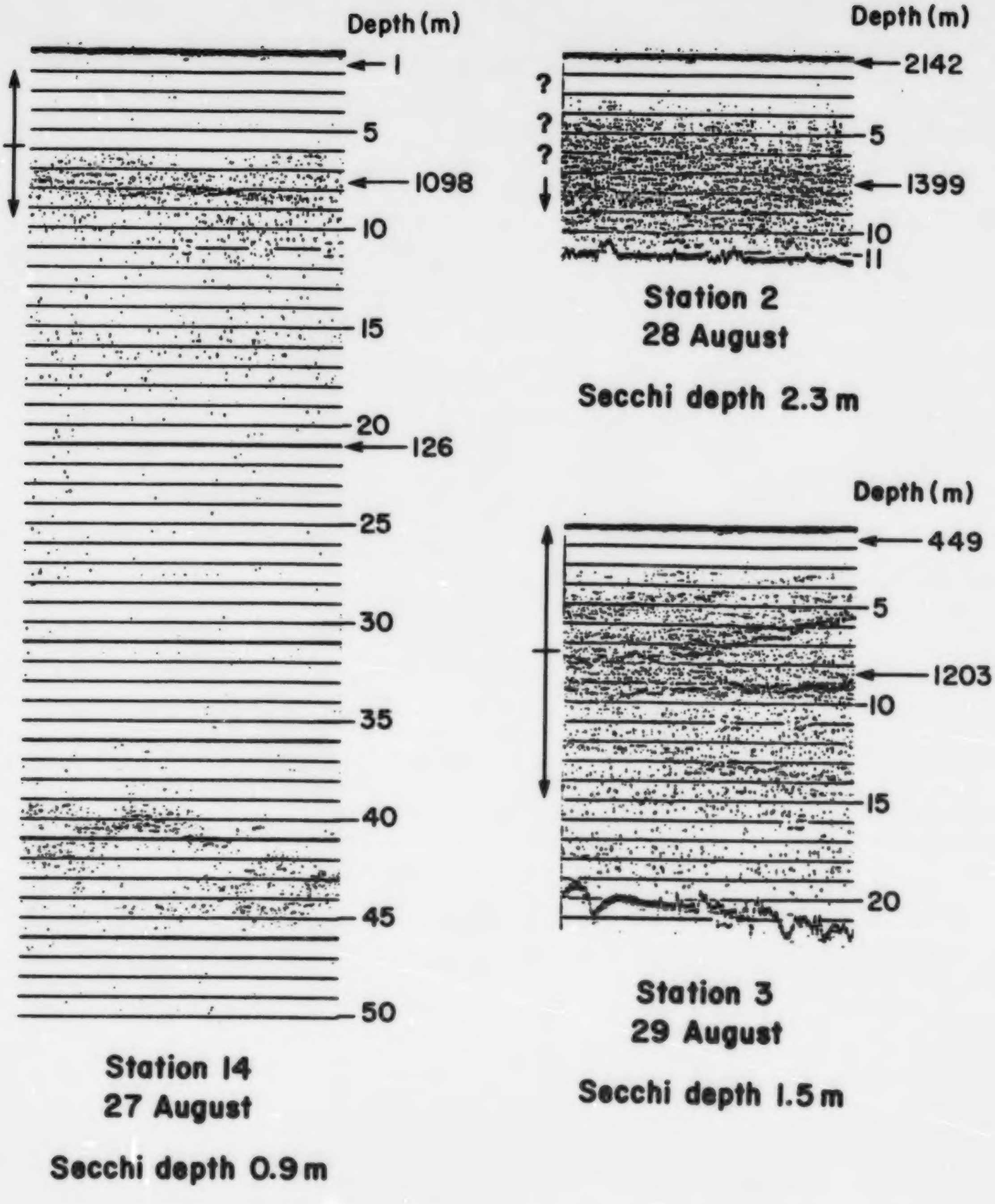
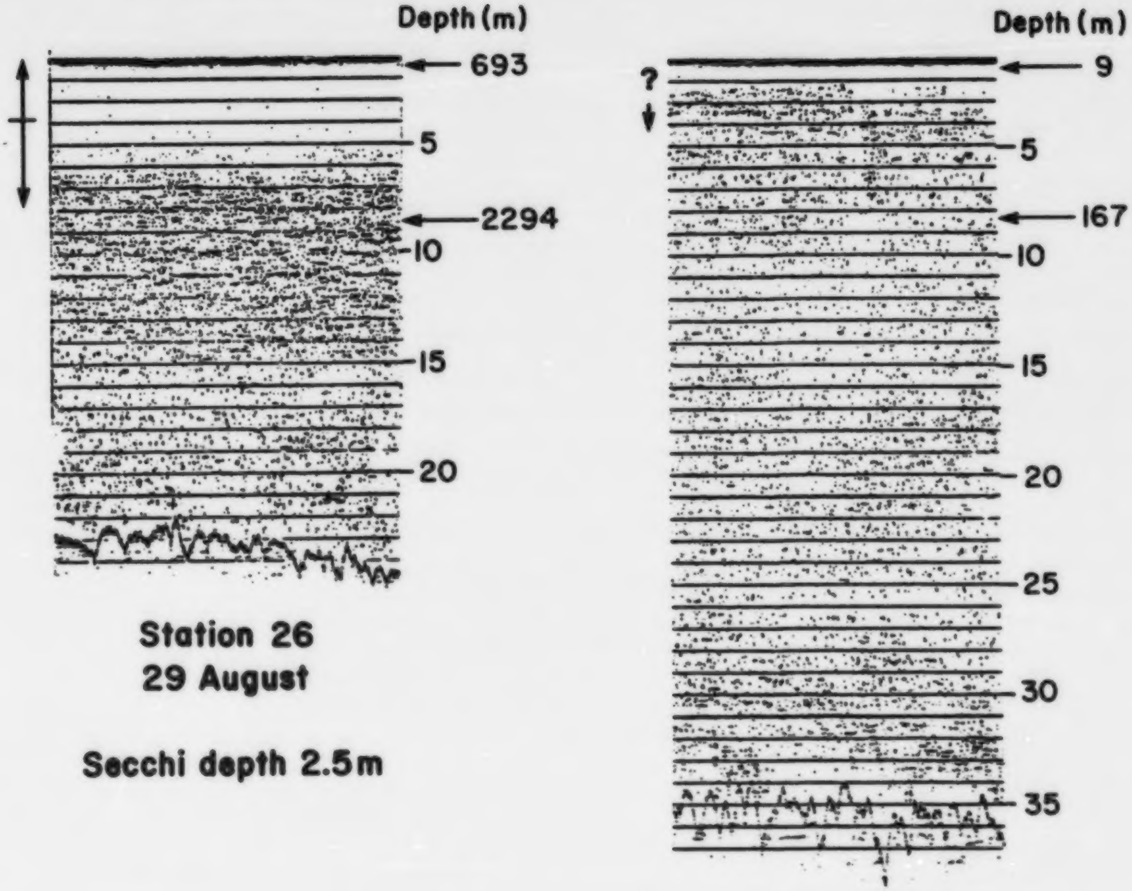


Figure 31. Echograms of potential prey patches at three stations where bowhead whales were apparently feeding. In this figure, water depths are indicated to the right of each column. Horizontal arrows point to depths and bands of echo where horizontal tows were made. The biomass of zooplankton (mg/m^3) caught in these tows is also given. Vertical arrows at the left of each column indicate the top and bottom of the thermocline; the horizontal bar indicates the mid point of the thermocline zone. '??' indicate no data. The dark jagged line at the bottom of the two right-hand columns is the bottom. At station 14, the bottom was at 64 m. Horizontal distances represented in each column are about 720 m.



Station 26
29 August

Secchi depth 2.5m

Station 27
29 August

Secchi depth 12.0m

Figure 32. Echograms of potential prey patches at station 26, where bowhead whales were apparently feeding, and at station 27, a nearby location where no bowhead whales were seen. Presentation as in Figure 31.

was located near a front between arctic and diffuse plume water; this front was visible on satellite imagery the previous day (Figs. 20 and 21). On 29 August, a very shallow layer of diffuse plume water (estimated depth 1.5 m) was present at the surface. A surface tow (at about 1 m depth) revealed a moderate amount of zooplankton (Fig. 31, 449 mg/m^3). The densest band of echo occurred between 4 and 10 m. A horizontal tow at 8.6 m depth was 1.3 m below the mid thermocline depth and sampled arctic water. The biomass of zooplankton in that sample was 1203 mg/m^3, mainly Limnocalanus (Table 14).

Stations 26 and 27.--On 29 August we encountered several whales feeding in calm water at station 26, east of Kay Point. Up to eight whales were present at the surface at a time, so it is probable that many whales were feeding in the immediate area. Whales surfaced within 10 m of the boat on three occasions. While several whales surfaced and dived repeatedly, others seemed to be swimming just below the surface. These latter whales did not assume a 'fluke-out' posture before disappearing and we observed successive 'boils' of water at the surface along the whales' directions of movement. These 'boils' were probably made by underwater fluke movements. Apparently, whales were feeding both near the surface and in the water column. Two whales surfaced along a visible discontinuity between waters of presumably different properties and we conducted zooplankton tows along this discontinuity. At the north end of the first zooplankton tow, a thin layer of mixed water (temperature from 3 to 5°C) was present at the surface (Fig. 23), but at the south end of this tow arctic water (<3°C) was present at the surface. Secchi depths were about 2.5 m. A dense band of echo was visible on the echogram between 5 and 15 m; less dense echo continued to the bottom at about 22 m (Fig. 32). We sampled the dense band at a depth of 8.3 m, at the bottom of the thermocline (Table 4) and recorded the highest amount of zooplankton found in the study (2294 mg/m^3). We steamed back along the surface discontinuity, in the direction from which we had come, and made a surface horizontal tow. Zooplankton biomass in the surface tow was 693 mg/m^3. At both depths, Limnocalanus constituted most of the biomass.

We steamed offshore (ENE) for about 3 km to control station 27. Arctic water was present at the surface and no strong thermocline was present (Fig. 23). The bottom of the weak thermocline (0°C) was estimated to be at about 4 m depth. Surface waters were very clear at this station and the secchi depth recorded was the deepest found during the study (12 m). No whales were visible in the area. A broad band of echo was visible on the echogram from 2 m down to the bottom (Fig. 32). We made horizontal tows at the same depths as at station 26 and, in comparison, found much smaller amounts of zooplankton (9 mg/m^3 at the surface; 167 mg/m^3 at a depth of 8.3 m).

Composition of Zooplankton Samples near Feeding Whales.--The relative composition of important taxa (zooplankton groups or copepod taxa forming >1% of total zooplankton biomass) in samples collected near apparently feeding whales is given in Tables 14 and 15. Based on the behaviour of whales observed at some stations and the absence of whales at station 27, the samples were classified as representing feeding or non-feeding situations. The sample collected at a depth of 1 m at station 3 was not classified to either group. There was no indication that whales were feeding near the surface at this station but zooplankton biomass was moderate. The sample collected at a depth of 21 m at station 14 was also not classified. While we cannot rule out that whales were diving to this depth to feed, it seems

Table 15. Composition of zooplankton samples collected at a location where whales were apparently feeding (station 26) and at a nearby control location (station 27).

Location	Sample depth (m)	Whales feeding?	Zooplankton biomass mg/m^3	Taxa comprising greater than 1% of biomass	%
Station 26	1	Yes	692.6	Copepoda	99.4
				Limnocalanus macrurus	90.8
				Calanus hyperboreus	5.4
				calanoid skeletons	1.9
	8.3	Yes	2294.3	Copepoda	98.1
				Limnocalanus macrurus	83.7
				calanoid skeletons	10.7
				Calanus hyperboreus	3.6
				Mysidacea	1.1
Station 27	1	No	8.8	Copepoda	44.4
				Calanus hyperboreus	21.8
				Pseudocalanus minutus	11.5
				Limnocalanus macrurus	8.5
				calanoid skeletons	1.3
				Hydrozoa	42.5
				Ctenophora	9.6
	8.3	No	166.9	Copepoda	91.8
				Limnocalanus macrurus	73.6
				Calanus hyperboreus	11.7
				Calanus glacialis	3.1
				Euchaeta glacialis	1.7
				Pseudocalanus minutus	1.5
				Hydrozoa	4.3
				Pteropoda	1.2

unlikely that they would do so when higher biomasses were available at shallower depths.

Presumed feeding samples were as diverse (mean of four important taxa per sample) as presumed non-feeding samples (mean of six taxa, U = 4, P = 0.3). The biomasses of all zooplankton were significantly greater in presumed feeding samples (mean of 1472 mg/m^3, SD = 625) than in presumed non-feeding samples (mean of 59 mg/m^3, SD = 94; U = 0, P = 0.02). The relative importance of *Limnocalanus macrurus* was greater in feeding samples (mean of 89%) than in non-feeding samples (46%; U = 0, P = 0.02). Conversely, *Calanus hyperboreus*, a species typically associated with arctic water (Grainger and Grohe 1975), was relatively less important in feeding samples (mean of 2%) than in non-feeding samples (18%; U = 0, P = 0.02). The relative proportions of calanoid skeletons were similar in the two groups (U = 3, P>0.1) and other taxa were too rare to permit meaningful comparisons.

Mean biomasses of *Limnocalanus macrurus* were greater in samples collected where whales were feeding (1312 mg/m^3, SD = 574) than in samples from non-feeding areas (41 mg/m^3, SD = 70; U = 0, P = 0.02). Mean biomasses of *Calanus hyperboreus* were not, however, different in the two types of samples (feeding: 25 mg/m^3, SD = 32; non-feeding: 7 mg/m^3, SD = 11; U = 10, P>0.1).

Drop Net Samples

Epibenthic invertebrates were sampled with drop nets at four stations: 1 (N = 9 samples), 5 (9), 7 (1) and 11 (9). Details of the composition of these samples are given in Appendix 5.

Drop nets sampled the water column on their descent, and this fact may account for the presence of hydrozoa, ctenophora, chaetognatha, and some calanoida in the samples (Table 16). When results from the 28 samples were averaged, mean total biomass was dominated by the isopod *Saduria entomon* (58%), followed by calanoids (15%), the mysid *Mysis litoralis* (13.8%), oedicerotids (5.2%), the chaetognath *Sagitta elegans* (4.6%) and eight other groups each comprising <1%.

We found no difference in the total biomasses occurring at the three stations with more than one sample (H = 2.9, P>0.1).

Table 16. Composition of drop net samples collected off the Yukon coast, August 1985.*

	Biomass (mg) per sample (N = 28)				
Taxon	Mean	SD	Total biomass	mg/m^2	% of total
Unidentified fragments	0.8	3.1	22.4	4.0	0.2
Hydrozoa	3.3	4.8	92.4	16.5	0.9
Aglantha digitale	3.1	4.8	86.8	15.5	0.8
Aeginopsis laurenti	0.2	0.6	5.6	1.0	0.1
Ctenophora	1.9	10.2	53.2	9.5	0.5
Beroe cucumis	1.9	10.2	53.2	9.5	0.5
Cydippida spp.	<0.1	0.2	<0.1	<0.1	<0.1
Chaetognatha	17.8	22.6	498.4	89.0	4.8
Eukrohnia hamata	0.7	1.7	19.6	3.5	0.2
Sagitta elegans	17.1	21.6	478.8	85.5	4.6
Pisces	0.7	3.8	19.6	3.5	0.2
Liparidae	0.7	3.8	19.6	3.5	0.2
Mysidacea	51.0	52.9	1428.0	255.0	13.8
Mysis litoralis	50.9	53.0	1425.2	254.5	13.8
Mysid spp.	0.1	0.6	2.8	0.5	0.0
Calanoida	53.8	34.8	1506.4	269.0	14.6
Harpacticoida	<0.1	0.2	<0.1	<0.1	<0.1
Hyperiidae	0.2	0.6	5.6	1.0	0.1
Parathemisto abyssorum	0.2	0.6	5.6	1.0	0.1
Gammaridea	22.0	45.0	616.0	110.0	6.0
Apherusa glacialis	1.1	2.3	30.8	5.5	0.3
Onisimus glacialis	1.6	4.9	44.8	8.0	0.4
Oedicerotidae	19.3	44.2	540.4	96.5	5.2
Polychaeta	2.5	9.4	70.0	12.5	0.7
Isopoda	213.8	513.4	5986.4	1069.0	57.9
Saduria entomon	213.8	513.4	5986.4	1069.0	57.9
Cumacea	1.3	4.0	36.4	6.5	0.4
All taxa	369.2	489.4	10337.6	1846.0	100.0

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* The drop net was 0.5 m in diameter and sampled 0.2 m^2 of bottom on each cast. The net also sampled the water column during its descent.

MEASUREMENTS AND LIFE STAGES OF SELECTED ZOOPLANKTON TAXA

Lowry and Frost (1984) have shown that, in the Alaskan Beaufort Sea, bowhead whales most commonly eat organisms that range in length from 3 to 30 mm. We measured potential food organisms collected off the Yukon coast in order to determine the abundances of various-sized prey in various water masses in our study area. We assumed that samples collected below the mid thermocline depth at locations with diffuse plume water at the surface were from arctic water. We made comparisons among three water masses: diffuse plume waters above the thermocline, arctic waters above the thermocline, and arctic waters below the thermocline. Data from oblique tows were not considered in such comparisons. Data from oblique tows were, however, tabulated in summaries of the lengths and life stages of taxa present in the whole study area.

Copepods

Copepods dominated zooplankton biomass in the study area (85% of biomass in oblique tows, 96-99% in surface horizontal tows, 76-92% in tows through suspected prey patches). We found a slight but significant difference in the mean lengths of all calanoid copepods between arctic waters above the thermocline (2.33 mm, SD = 1.30, N = 558) vs. below it (2.65 mm, SD = 1.26, N = 797; z = 2.08, P = 0.04). There was a small but highly significant difference in the mean lengths of all calanoids between diffuse plume waters (2.06 mm, SD = 1.20, N = 540) and all arctic waters (2.52 mm, SD = 1.29; z = 3.59, P<0.001).

Three calanoids (Limnocalanus macrurus, Calanus hyperboreus and Calanus glacialis) dominated copepod biomass. We expected that there might be differences in the lengths of these species between water masses, a reflection of possible differences in nutrient and food levels between relatively fresh plume water and relatively saline arctic water. We were, however, unable to demonstrate such differences. The lengths of particular life stages of these three dominant copepods did not differ between arctic waters and diffuse plume waters (Table 17) or between arctic waters above and below the thermocline (P>0.1 in 11 similar comparisons). We also compared the life-stage frequency distributions of these three dominant copepods between diffuse plume and arctic waters (Fig. 33). While there were some minor differences in the relative abundances of particular life stages between the two water masses, the frequency distributions were similar for each copepod species (Kolmogorov-Smirnov P>0.1 using the number of samples in which the species was present as N).

Generally, the differences in average copepod lengths between diffuse plume and arctic waters, although statistically significant, were small (less than 0.5 mm). It seemed possible that these small differences could have come about through a differential distribution of large and small life-stages of copepods in the two main water masses. We determined the mean length for each life stage of each species of copepod, using material from all zooplankton samples (Table 18), and then constructed a length frequency distribution of copepods in the two main water masses (Fig. 34). This frequency distribution was based on the numbers, and not biomasses, of each copepod species.

Table 17. Lengths of copepods (mm) in diffuse plume and arctic waters off the Yukon coast, August 1985.

		Diffuse plume water			Arctic water			
Species	Life stage	Mean length	SD	Number measured	Mean length	SD	Number measured	t
Calanus hyperboreus	III	2.26	.15	7	2.30	.19	92	-.04
	IV	3.35	.20	16	3.33	.19	112	.02
	V	4.90	.29	16	4.76	.31	50	.10
	Ad. F	6.55	.42	10	6.45	.30	61	.04
Calanus glacialis	II	-	-	-	1.20	-	1	-
	III	1.79	.08	9	1.71	.12	21	.11
	IV	2.45	.11	21	2.41	.13	79	.07
	V	3.20	.16	13	3.26	.22	80	-.06
	Ad. F	3.92	.21	18	3.89	.21	102	.03
	Ad. M	-	-	-	3.70	-	1	-
Limnocalanus macrurus	V	1.33	.09	104	1.34	.25	39	-.40
	Ad. F	1.84	.09	140	1.89	.08	270	-.26
	Ad. M	1.69	.08	140	1.73	.07	270	-.22

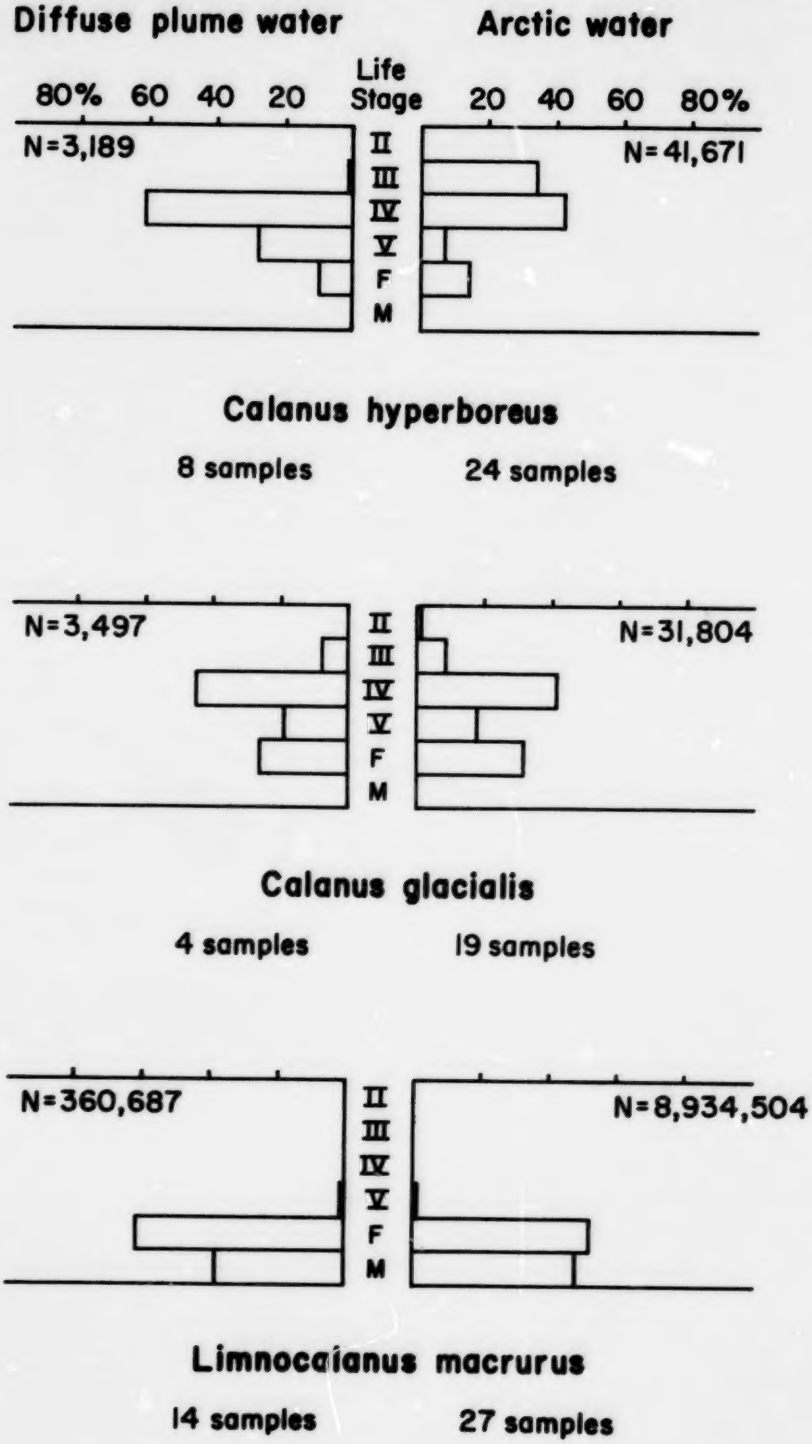

Figure 33. Life-stage frequency distributions of three dominant copepods in horizontal bongo tows off the Yukon coast, August 1985.

Table 18. Lengths (mm) and estimated biomasses of copepods collected off the Yukon coast, August 1985.*

Species	Life stage	Mean length	SD	Number measured	Estimated individual biomass (mg)
Calanus hyperboreus (N = 762)	II	1.75	.64	2	.16
	III	2.28	.20	223	.52
	IV	3.30	.20	271	1.27
	V	4.76	.34	126	5.34
	Ad. F	6.48	.31	140	14.86
Calanus glacialis (N = 799)	II	1.25	.14	30	.16
	III	1.74	.12	112	.26
	IV	2.41	.15	221	.74
	V	3.28	.21	195	2.03
	Ad. F	3.90	.11	234	3.77
	Ad. M	3.70	.15	7	3.43
Derjuginia tolli (N = 50)	IV	1.35	.07	21	.20
	V	1.59	.11	28	.46
	Ad. M	1.80	–	1	.40
Limnocalanus macrurus (N = 1380)	IV	1.10	.08	4	.11
	V	1.33	.14	216	.19
	Ad. F	1.87	.09	580	.46
	Ad. M	1.71	.07	580	.34
Pseudocalanus minutus (N = 270)	IV	.90	–	1	.02
	V	1.14	.07	10	.04
	Ad. F	1.19	.51	248	.14
	Ad. M	1.09	.08	11	–
Metridia longa (N = 80)	II	1.10	–	1	–
	III	1.10	.08	4	.07
	IV	1.49	.17	12	.26
	V	2.01	.11	15	.78
	Ad. F	2.82	.12	46	1.93
	Ad. M	2.20	0.00	2	1.00
Euchaeta glacialis (N = 92)	I	1.20	–	1	.08
	II	1.47	.05	11	.14
	III	2.19	.08	18	.58
	IV	3.18	.20	23	2.50
	V	4.79	.24	20	6.57
	Ad. F	6.67	.32	19	9.30
Chiridius obtusifrons (N = 3)	V	2.30	0.00	2	–
	Ad. F	3.20	–	1	–
Centropages hamata (N = 9)	V	1.30	–	1	–
	Ad. F	1.15	.05	6	–
Acartia longiremis (N = 2)	Ad. F	1.00	0.00	2	–
Eurytemora spp. (N = 5)	Ad. F	1.15	.07	2	–
	Ad. M	1.03	.06	3	–

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* Roman numerals refer to copepodite stages, Ad. F = adult female, Ad. M = adult male. 3452 copepods were measured. Estimated biomass was determined from the total biomass of each life stage in all zooplankton samples divided by the total number.

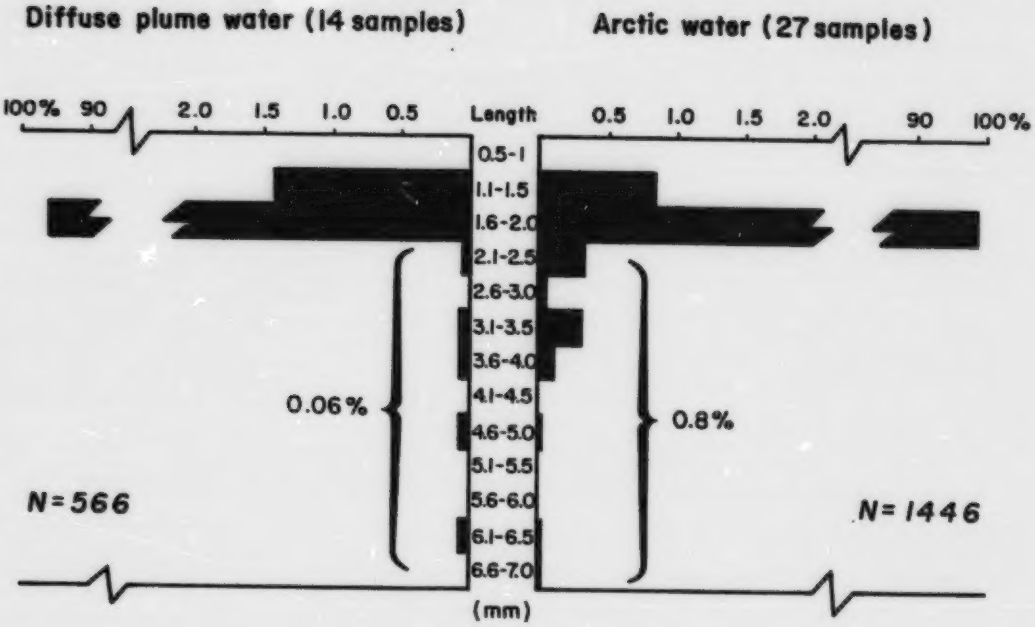

Figure 34. Length-frequency distributions of measured copepods in horizontal bongo tows off the Yukon coast, August 1985. Unmeasured copepod skeletons were not considered.

The copepod population in each water mass largely consisted of individuals <2 mm in length. These small items were mostly adult male and female Limnocalanus macrurus and adult female Pseudocalanus minutus. Together, these three taxa made up 99.3% of items <2 mm in length in diffuse plume water and 99.8% of those in arctic water. Larger-sized copepods (>2 mm) were rare in both water masses, but on a proportional basis they were 13 times more abundant in arctic water than in diffuse plume water (Fig. 34). The differential distribution of large copepods between diffuse plume and arctic waters probably accounted for the small but significant difference in mean copepod lengths that was observed. A similar explanation probably also accounts for the significant difference in mean copepod length between samples taken above and below the thermocline in arctic waters.

Life-stage frequency distributions of selected copepod species are presented in Figure 35. These distributions were determined from all zooplankton samples. Distributions were weakly to moderately bimodal for Calanus hyperboreus and C. glacialis, suggesting a two-year life cycle in the study area. Distributions for Metridia longa and Euchaeta glacialis were unimodal. The distributions of the other species presented in Figure 35 must be interpreted with some caution, since the younger life stages may not have been adequately sampled with our gear (net mesh size 0.5 mm). The preponderance of adult Limnocalanus macrurus is, however, consistent with the known one-year life cycle of this species elsewhere (Carter 1969).

Other Zooplankton

We looked for differences in the mean lengths of selected zooplankton taxa between water masses based on samples collected from horizontal tows. We were unable to demonstrate any such differences, either between diffuse plume and arctic waters or between arctic waters above and below the thermocline (Table 19, $P>0.1$ in 18 comparisons). Almost all of the taxa in Table 19 were much more common in arctic than in diffuse plume waters.

The mean lengths and estimated individual weights of all items measured are given in Table 20. Length frequency distributions are given in Figure 36. Mean lengths varied from 1.7 mm (Spiratella helicina) to 45.5 mm (young salmonid). Most frequency distributions were unimodal; the bimodal distributions of Onisimus glacialis, O. nanseni, and possibly Mysis litoralis reflect the known two-year life cycles of these species in nearshore Beaufort Sea waters (Griffiths and Dillinger 1981). Several other zooplankters (the chaetognaths Eukrohnia hamata and Sagitta elegans, the amphipod Apherusa glacialis, and the euphausiids Thysanoessa raschii and T. inermis) had unimodal distributions which suggest one-year life cycles. Only small Parathemisto were captured with our sampling gear; some adults are known to reach 60 mm in length, and Parathemisto have a two-year life cycle in arctic waters (Dunbar 1957). Hyperiid amphipods found in the stomachs of bowheads taken near Kaktovik were 8-21 mm in length (Lowry and Frost 1984).

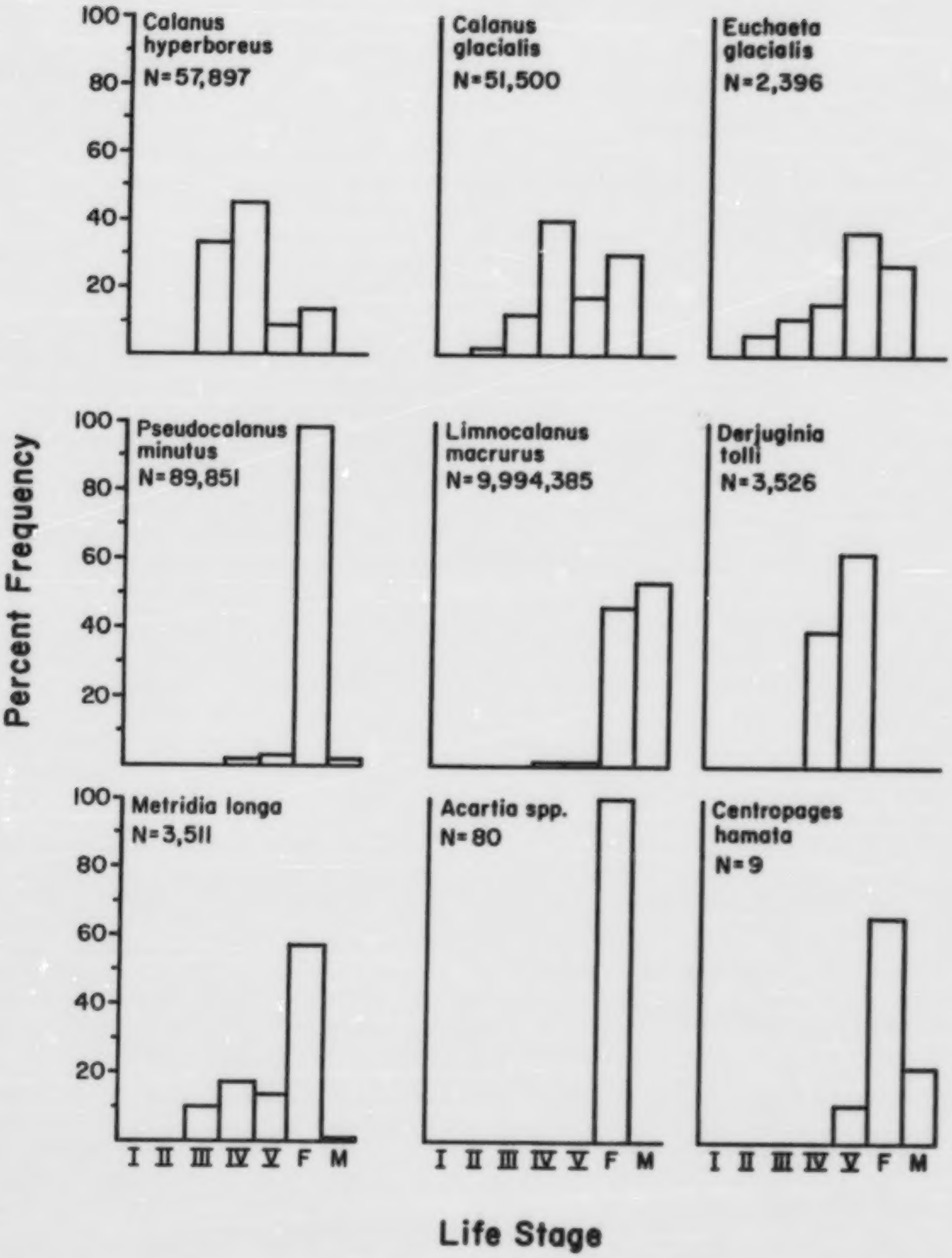

Figure 35. Life-stage frequency distributions of selected copepod species collected off the Yukon coast, August 1985. N = estimated numbers present in all tows.

Table 19. Lengths (mm) of selected zooplankton taxa in diffuse plume and arctic waters off the Yukon coast, August 1985.

	Diffuse plume water			Arctic water			
Taxon	Mean length	SD	Number measured	Mean length	SD	Number measured	t
Pteropoda							
Spiratella helicina	1.7	1.0	9	2.0	.7	178	-.41
Clione limacina	-	-	-	2.9	5.3	16	-
Chaetognatha							
Eukrohnia hamata	14.5	20.1	2	15.5	3.7	105	-.09
Sagitta elegans	20.7	4.4	13	24.6	4.7	228	-.55
Sagitta spp.	-	-	-	24.2	4.3	84	-
Pisces							
Gadidae	19.1	3.2	54	21.1	4.1	84	-.56
Cottidae	-	-	-	18.3	2.5	52	-
Liparidae	23.0	8.5	2	21.7	5.8	18	.07
Stichaeidae	34.5	-	1	28.7	3.2	22	.19
Mysidacea							
Mysis litoralis	11.9	4.4	20	11.3	4.4	184	.21
Mysis oculata	20.0	-	1	20.4	1.6	10	-.02
Euphausiacea							
Thysanoessa raschii	18.0	-	1	19.2	3.8	92	-.06
Thysanoessa inermis	-	-	-	18.7	2.2	39	-
Decapoda							
Decapod spp.	-	-	-	7.7	.8	23	-
Crangonid spp.	12.8	1.5	16	13.2	1.1	101	-.11
Hyperiidae							
Hyperia galba	6.5	.5	5	7.3	1.8	97	-.23
Parathemisto abyssorum	-	-	-	4.1	1.3	96	-
Parathemisto libellula	10.3	1.9	10	13.9	2.7	112	-.78
Gammaridea							
Apherusa glacialis	7.8	2.3	3	7.4	2.1	114	.09
Onisimus glacialis	10.2	1.0	3	7.7	18.4	103	.21
Onisimus nanseni	8.0	-	1	9.3	2.5	34	-.13

Table 20. Lengths (mm) and estimated biomasses of selected zooplankton taxa collected off the Yukon coast, August 1985.*

Estimated Taxon	Mean length	SD	Number measured	Individual biomass (mg)
Pteropoda (N = 357)				
Spiratella helicina	1.7	0.8	336	4.5
Clione limacina	3.1	5.1	21	31.0
Chaetognatha (N = 713)				
Eukrohnia hamata	14.6	3.7	202	4.8
Sagitta elegans	24.3	4.8	391	13.2
Sagitta maxima	37.0	-	1	-
Sagitta spp.	22.5	6.1	112	5.4
Chaetognath spp.	15.8	5.4	7	2.0
Pisces (N = 323)				
Gadidae	20.1	3.9	203	55.2
Cottidae	18.5	2.5	61	50.9
Liparidae	22.2	5.5	30	172.3
Salmonidae	45.5	-	1	821.0
Stichaeidae	28.7	3.2	28	33.7
Mysidacea (N =349)				
Mysis litoralis	11.3	4.2	291	20.1
Mysis oculata	20.3	1.5	12	80.1
Mysis spp.	10.3	2.4	46	9.2
Euphausiacea (N = 199)				
Thysanoessa raschii	19.3	3.7	139	49.7
Thysanoessa inermis	18.3	2.2	60	50.7
Decapoda (N = 242)				
Decapod spp.	8.7	2.3	42	3.4
Crangonid spp.	13.1	1.1	200	11.5
Hyperiidae (N = 497)				
Hyperia galba	7.1	1.8	123	10.1
Hyperia spp.	2.0	0.0	3	1.0
Hyperoche medusarum	25.0	-	1	-
Parathemisto abyssorum	3.9	1.2	165	1.6
Parathemisto libellula	13.1	2.8	203	30.1
Hyperiid spp.	2.0	0.0	2	1.0
Gammaridea (N = 371)				
Apherusa glacialis	7.5	2.1	154	9.8
Apherusa spp.	8.1	2.3	7	15.1
Onisimus glacialis	8.0	3.3	150	15.2
Onisimus nanseni	9.4	3.0	49	33.3
Onisimus spp.	4.5	0.9	3	1.0
Gammarus wilkitzkii	26.5	13.2	4	215.0
Gammarus spp.	8.0	-	1	7.0
Gammaracanthus loricatus	11.0	0.0	3	11.0
Other Zooplankton (N = 9)				
Munopsis typica	12.5	0.7	2	21.0
Ostracod spp.	1.5	0.7	2	1.0
Cypris nauplii	1.0	-	1	1.0
Ophiuroid spp.	1.0	1.0	4	0.3

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* 3060 items were measured. Biomasses were determined from measured items.

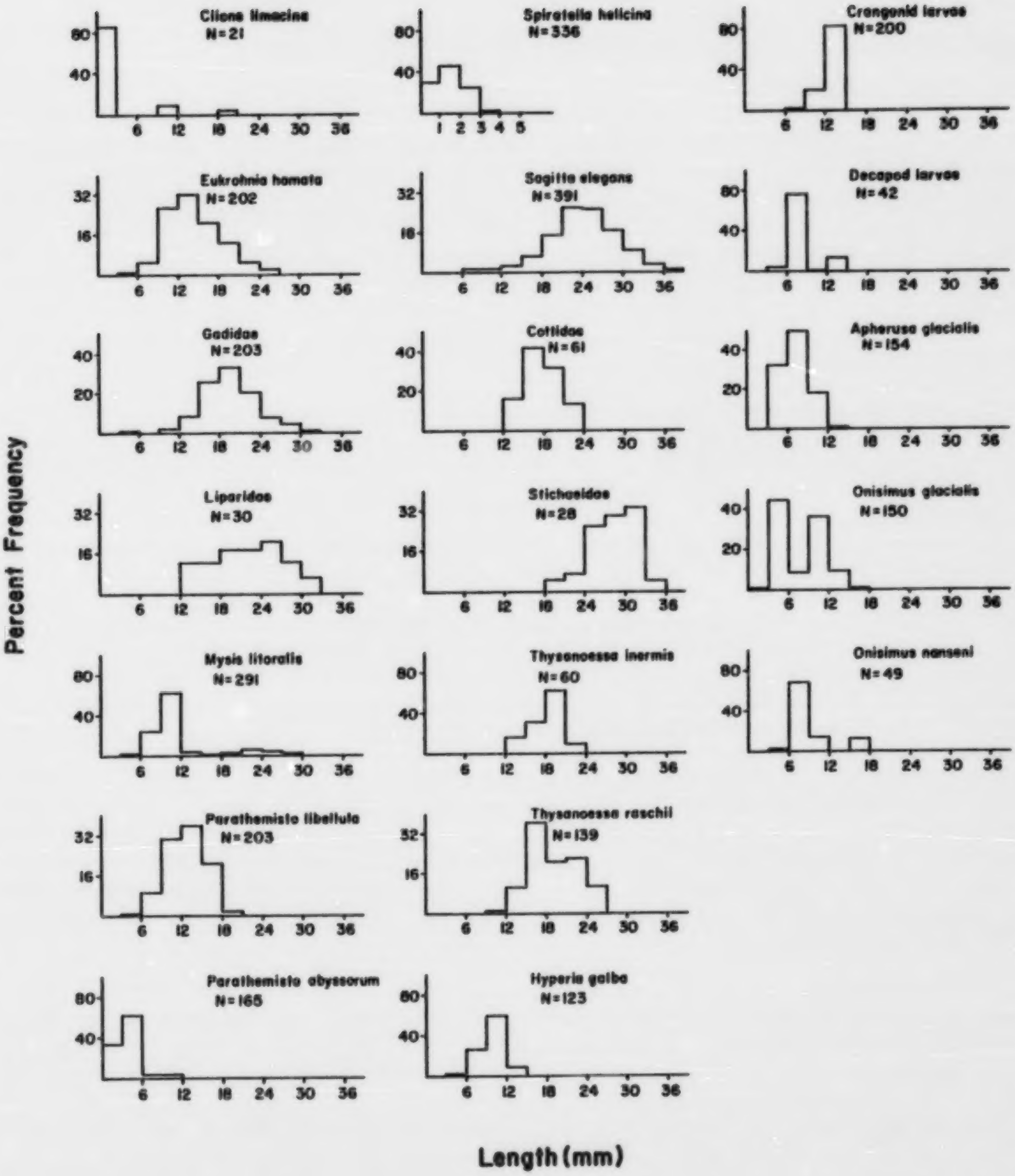

Figure 36. Length-frequency distributions of selected zooplankton taxa collected off the Yukon coast, August 1985. Note that axes vary.

CALORIC AND LIPID CONTENT OF THE ZOOPLANKTON

The summer growing period for arctic phytoplankton is brief and during this period herbivorous zooplankters must store enough energy to survive the long winter period of food scarcity (Lee 1974). Zooplankters store energy in the form of lipids (Raymont 1983). Early in the spring, zooplankters have very low lipid and thus energy levels, but by late summer lipid and energy levels are at an annual high (Lee 1974). Feeding in the late summer and early fall periods may be especially important to bowhead whales because of the high energy content of zooplankton at that time of year (Lowry and Frost 1984).

Caloric Determinations

We assessed the relative amounts of energy potentially available to bowhead whales in different water masses. Caloric determinations were made on all samples for which adequate amounts of zooplankton were available (N = 39 samples). Zooplankton material was homogenized before caloric determinations were made and the resulting values represent the amount of energy available in the samples regardless of their composition. Samples were organized on the basis of tow type (oblique vs. horizontal), water mass sampled by horizontal tows (diffuse plume vs. arctic waters), and position with respect to the thermocline (above vs. below). Caloric values per gram dry weight were converted to calories per gram wet weight using an appropriate correction factor determined from the group composition of the sample and the percentage of each group that was water. These values were then converted to potential calories available per cubic metre of water. Only samples for which all data were available were considered (N = 38).

The energy values of zooplankton in all collections were similar, with averages ranging from 6547-6850 cal./g dry weight (Table 21). Energy values per unit wet weight were similar above and below the thermocline in arctic waters as were unit biomasses (Table 22). Consequently, potential amounts of energy available per cubic metre were also similar above and below the thermocline (Table 22, $P>0.1$).

We compared the potential energy available in arctic and diffuse plume waters, based on horizontal tows (Tables 21 and 22). Unit energy values were similar in the two water masses but unit biomasses were 3.6 times greater in samples collected in arctic waters than in those collected in diffuse plume waters. The result was that the potential energy available to bowheads on a unit volume basis was significantly higher in arctic waters (835 cal./m^3) than in diffuse plume waters (223 cal/m^3).

Average amounts of energy potentially available to bowhead whales in the upper water column (as determined by oblique tows through the upper 10-35 m, 306 cal./m^3) did not differ from amounts available in potential prey patches in diffuse plume waters ($t = 0.68$, $P>0.1$) but were significantly less than amounts available in all arctic waters (variances unequal, $t = 2.95$, d.f. = 32).

Table 21. Caloric values of zooplankton samples collected off the Yukon coast, August 1985.

			Potential Prey Patches							
			Diffuse plume waters		Arctic waters					
	Oblique Tows		Above thermocline		Above thermocline		Below thermocline		All	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Cal./g dry weight	6656.5	360.3	6849.5	210.4	6546.6	578.6	6796.6	497.6	6677.6	540.8
Dry weight/wet weight (%)	16.5		16.5		16.9		16.7		16.8	
Cal./g wet weight	1098.3	67.4	1130.2	34.7	1106.4	97.8	1135.2	83.1	1121.4	89.5
Biomass (mg)/m^3	275.3	273.0	200.7	190.9	906.1	521.5	560.4	674.2	725.7	618.1
Cal./m^3	305.8	308.3	223.4	211.6	1011.7	589.4	672.7	841.2	834.8	736.0
No. caloric determinations	31		12		39		29		68	
No. samples	11		4		11		12		23	

Table 22. Comparisons of amounts and energetic values of zooplankton between various water masses. See Table 21 for data.

Comparison	t	d.f.	P
Arctic waters: above vs. below thermocline			
Cal./g dry weight	-1.18	21	>0.1
Cal./g wet weight	-.76	21	>0.1
Biomass (mg)/m^3	1.37	21	>0.1
Cal./m^3	1.09	21	>0.1
Diffuse plume vs. all arctic waters			
Cal./g dry weight	.62	25	>0.1
Cal./g wet weight	.91	25	>0.1
Biomass (mg)/m^3	-3.27*	22	<0.01
Cal./m^3	-3.28*	23	<0.01

* t computed for unequal sample variances in this comparison.

On a unit dry weight basis, the four primary categories of samples contained similar amounts of energy (ANOVA F = 0.81; d.f. = 3, 35; P>0.1). The differences observed were largely due to the differing amounts of zooplankton available in the different collections.

Caloric determinations were also made on various specific taxa and size ranges of zooplankton. Copepods were further grouped by location: 'inshore locations' were the innermost two stations on each transect line; 'offshore locations' were the outermost station on each line (Fig. 1a). Copepods from station 26 were analyzed separately since there was good evidence that bowhead whales were feeding at that location (see above).

'Small' copepods were those <1.8 mm in cephalothorax length. Given the mean lengths of various copepod species and life stages measured during this study, and their frequencies of occurrence in the samples, the predominant taxa in this small size class were Limnocalanus macrurus and Pseudocalanus minutus (mean length of L. macrurus adult females was 1.9 mm; mean lengths of all other life stages of the two species were 1.7 mm or less). Other 'small' items included the younger life stages of Metridia longa (up to stage IV), Euchaeta glacialis (II), Calanus glacialis (III), Calanus hyperboreus (II); and all life stages of several relatively rare but small species (Acartia longiremis, Centropages hamata, Derjuginia tolli, and Eurytemora spp.). 'Large' copepods (>4 mm) included some adult male and female Calanus glacialis (mean lengths >3.7 mm), and probably stage V and adult female Calanus hyperboreus and Euchaeta glacialis (mean lengths >4.7 mm for stage 5 copepodites and >6.4 mm for females). Too few copepods of intermediate lengths (1.9-4.0 mm) were available for analysis.

There was no significant difference in the unit caloric values of small copepods from inshore locations vs. from station 26 (t = 1.68, d.f. = 7, P>0.1). While unit caloric values of these samples combined were less than those of small offshore copepods (t = -3.45, d.f = 9, P<0.01), the number of offshore samples was small (2). Large copepods did not differ from small copepods in their unit caloric values at inshore stations (t = -0.25, d.f. = 4, P>0.1) or when all stations were combined (t = -0.27, d.f. = 12, P>0.1).

Copepods had higher unit energy values (overall mean of 6846 cal./g dry weight, SD = 149, N = 14) than did the other taxa measured (Table 23). In descending order of caloric value, copepods were followed by hyperiids (6028 cal./g dry weight), hydrozoans (5784), mysids (5370), gadid young-of-the-year (5261) and euphausiids (5144). Although sample sizes were small, unit caloric values of small mysids (<15 mm in length) were significantly greater than those for large mysids (15+ mm, t = 16.2, P<0.01). There were no apparent differences in the unit energy values of small vs. large Parathemisto spp. or euphausiids.

Lipid Determinations

Much of the energy present in high latitude zooplankton is stored as lipid (Lee 1974, 1975; Clarke 1984; Head and Harris 1985). Generally, species that overwinter as large copepodites or adults build up lipid reserves during the short summer period and then metabolize these reserves during the long winter (Lee 1974). Lee (1974) found that in August, Calanus hyperboreus had extremely high amounts of storage lipids (74% of dry

Table 23. Caloric values of zooplankton taxa collected off the Yukon coast, August 1985.

Taxon	Size	Source	Cal./g dry weight Mean	SD	N	% water
Copepoda	Small (<1.8 mm)	Inshore locations	6852	96	4	84
		Station 26	6732	114	5	82
		Offshore locations	7089	55	2	86
	Large (>4 mm)	Inshore locations	6876	150	2	84
		Station 26	6850	-	1	79
Mysidacea	Small (<15 mm)	All stations	5679	34	2	86
	Large (15+ mm)	All stations	5060	42	2	83
Euphausiacea	Small (<20 mm)	All stations	5167	-	1	87
	Large (20+ mm)	All stations	5133	83	2	86
Parathemisto spp.	Small (<15 mm)	All stations	5947	140	2	86
	Large (15+ mm)	All stations	6190	-	1	86
Gadidae YOY	Small (<20 mm)	All stations	5261	-	1	88
Hydrozoa	All	All stations	5784	125	3	92

weight) and that in September, wax esters formed 91% of lipid weight. By October, Lee (1975) found that typical high-arctic over-wintering copepod species such as Calanus hyperboreus, C. glacialis, M. longa and Euchaeta glacialis had somewhat lower (but still high on a yearly basis) contents of storage lipids (43-64% of dry weight) which were primarily wax esters (72-84% of lipid content). Apparently, lipid content peaked in August-September for the species studied by Lee.

We analyzed several samples of zooplankton collected off the Yukon coast for lipid content and lipid composition (Table 24). Samples available for lipid determinations were frozen on collection and specific taxonomic determinations were not made. Species composition of the samples was assumed to be similar to that collected in paired bongo samples.

Samples were chosen for analysis based on the amount of material available, and the locations where the samples were collected (i.e., areas where whales were apparently feeding [N = 4] and areas where no whales were seen [N = 3]).

Lipids comprised 39% of the dry weight of zooplankton in apparent whale feeding areas and 35% in areas with no whales. The difference was not significant (F = 1.65, t = 0.45, d.f. = 5, P>0.1). The relative composition of the lipids was also generally similar in the two groups of samples (all t-test P>0.1), with wax esters predominating (56-69% of lipid weight). Both the percentage lipid and the percentage wax were lower than the values found by Lee (1974, 1975).

Zooplankton samples were composed largely of copepods (97% of wet weight biomass in apparent whale feeding areas, 85% in areas where no whales were seen) and primarily of Limnocalanus macrurus (87% of total biomass in apparent feeding areas, 71% in areas with no visible whales). The sample with the highest proportional biomass of L. macrurus (91%) had the lowest proportional amount of lipid (28%). This fact, combined with overall dominance of L. macrurus and the low amounts of lipid found at a time (August) when some copepod species contain large amounts, suggests that L. macrurus may not store lipid for over-wintering purposes. This would be consistent with a 1-year life cycle of this species in the study area (see above). Based on information given in Table 24, it seems that most of the lipid present in L. macrurus is wax ester.

A bowhead whale faecal sample collected at Isabella Bay, Baffin Island, on 10 September 1984 by K.J. Finley and C.R Evans (LGL Ltd.) was also analyzed for lipid composition. In three replicates, wax esters formed 59% (SD = 7%) of total lipid, triacylglycerols formed 8% (SD = 1%), fatty acids formed 5% (SD = 0.2%), and complex lipids formed 25% (SD = 1%). Ten vertical zooplankton samples collected in Isabella Bay in 1984 were dominated in biomass by copepods (K.J. Finley, pers. comm.). Stage V and adult life stages of Calanus hyperboreus and C. glacialis formed 51% of the 1576 copepods enumerated. Since the large life stages of these two species are known to contain much lipid (primarily wax esters) at this time of year, the faecal analyses suggest that wax esters are being utilized in rough proportion to the amounts ingested.

Table 24. Composition of samples analyzed for lipid content.

Parameter	Apparent Whale Feeding Areas				Mean	SD
Station	14	2	26	26		
Sample depth (m)	7.9	7.7	8.3	1.0		
Biomass (mg)/m^3	1098	1399	2294	693	1371	680
% Composition						
All copepoda	94.6	95.1	98.1	99.4	96.8	2.3
Calanus hyperboreus	1.8	2.3	3.6	5.4	3.3	1.6
Calanus glacialis	2.8	0.0	0.0	.8	.9	1.3
Limnocalanus macrurus	82.7	89.6	83.7	90.8	86.7	4.1
calanoid skeletons	7.3	2.3	10.7	1.9	5.6	4.2
Lipid (% of dry weight)	48.8	31.6	46.4	28.0	38.7	10.4
% Composition*						
wax fraction	64.1	69.3	57.0	66.7	64.3	5.3
triacylglycerol fraction	11.8	8.6	6.1	6.1	8.2	2.7
fatty acid fraction	15.2	6.8	7.5	7.6	9.3	4.0
phospholipid fraction	6.8	10.1	16.0	12.2	11.3	3.9
complex lipid fraction	2.2	5.2	13.4	7.4	7.1	4.7

Parameter	No Whales Seen			Mean	SD
Station	17	4	4		
Sample depth (m)	1.0	8.3	18.1		
Biomass (mg)/m^3	444	335	217	332	114
% Composition					
All copepoda	97.9	84.8	72.9	85.2	12.5
Calanus hyperboreus	12.8	1.4	5.9	6.7	5.7
Calanus glacialis	.4	6.3	5.6	4.1	3.2
Limnocalanus macrurus	84.1	71.1	57.0	70.7	13.6
calanoid skeletons	0.0	5.9	.2	2.0	3.4
Lipid (% of dry weight)	32.9	28.8	44.4	35.4	8.1
% Composition*					
wax fraction	56.1	64.2	66.7	62.3	5.5
triacylglycerol fraction	6.1	8.4	6.8	7.1	1.2
fatty acid fraction	7.7	7.4	13.3	9.5	3.3
phospholipid fraction	10.9	15.5	10.9	12.4	2.7
complex lipid fraction	19.2	4.5	2.3	8.7	9.2

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* Lipids are composed of four fractions as listed. Wax fraction includes alkanes, wax esters and cholesterol esters (in these samples wax esters compose >95% of this fraction); fatty acid fraction includes diacylglycerols, monoacylglycerols, fatty alcohols, carotenoids and cholesterol. Phospholipid fraction was determined from measurement of organic phosphorus.

HYDROACOUSTIC SAMPLING

Hydroacoustic sampling was conducted during most zooplankton tows and during periods of travel between sampling stations. Hydroacoustic surveys provided information on zooplankton at far more locations and depths than could be sampled with traditional net-sampling methods. However, before the hydroacoustic data can be interpreted, it is necessary to understand the relationships between the hydroacoustic data and the amounts of zooplankton estimated with net sampling.

Three types of net sampling were conducted: oblique tows through the upper 10-35 m of the water column, horizontal 'surface' (1 m depth) tows, and horizontal tows at greater depths. Because the transducer was mounted at 1 m depth, no hydroacoustic information comparable to the 'surface' tows was obtained. For the remaining oblique (N = 8) and horizontal (N = 20) tows, the density of hydroacoustic echo was estimated on an ordinal scale of 0 to 9 for each 1-m depth interval. For each horizontal tow at depth, the estimated echo density was recorded for the specific 1-m depth interval in which the horizontal zooplankton tow was taken (depth determined by the upward-pointing transducer mounted on the sampling gear) and for adjacent 1-m intervals above and below the nominal sampling depth. Two averages were then derived, for the zones from 1 m above to 1 m below the sampling depth, and from 2 m above to 2 m below the sampling depth.

Hay (1984) has shown that a 200 kHz echosounder detected density contrasts in arctic waters. Similarly, Penrose and Beer (1981) found that acoustic scattering from the pycnocline in estuarine waters was attributable to temperature-salinity gradients. We were unable to directly determine pycnocline depth in this study because the conductivity probes on our sampling equipment malfunctioned. We were, however, able to collect relative salinity information. This information corroborated the likelihood that the thermocline coincided with the pycnocline. Following Griffiths et al. (1986), we eliminated from consideration those horizontal tow samples collected near the thermocline and the associated echosounder data. In such situations, high densities of echo likely represented the pycnocline, and not concentrations of zooplankton. We also eliminated those horizontal samples and echosounder data collected at stations where information on the position of the thermocline was questionable.

The remaining ordinal estimates of echo density were then compared with results from net sampling. We used the biomass of zooplankton/m^3, not the numerical density of zooplankton, since echo density is more closely related to biomass than to numbers (Greenlaw et al. 1980; Thorne 1983; Griffiths et al. 1986). Non-parametric (Spearman) tests were used to test relationships.

There was a significant correlation ($r_s = 0.77$) between ordinal estimates of echo intensity and the biomasses of zooplankton found in those horizontal tows made more than 1.25 m away from the thermocline (Fig. 37). In this comparison, the specific 1-m depth intervals in which horizontal tows were made were considered. The strength of the relationship was reduced when correlations were based on estimates of echo intensity versus results from either the 3 m or 5 m strata within which horizontal tows were centred (r_s = 0.55 and 0.45, respectively). Similarly, when additional horizontal tows taken only 0.5 to 1.25 m from the thermocline were considered, the overall strength of the relationship decreased.

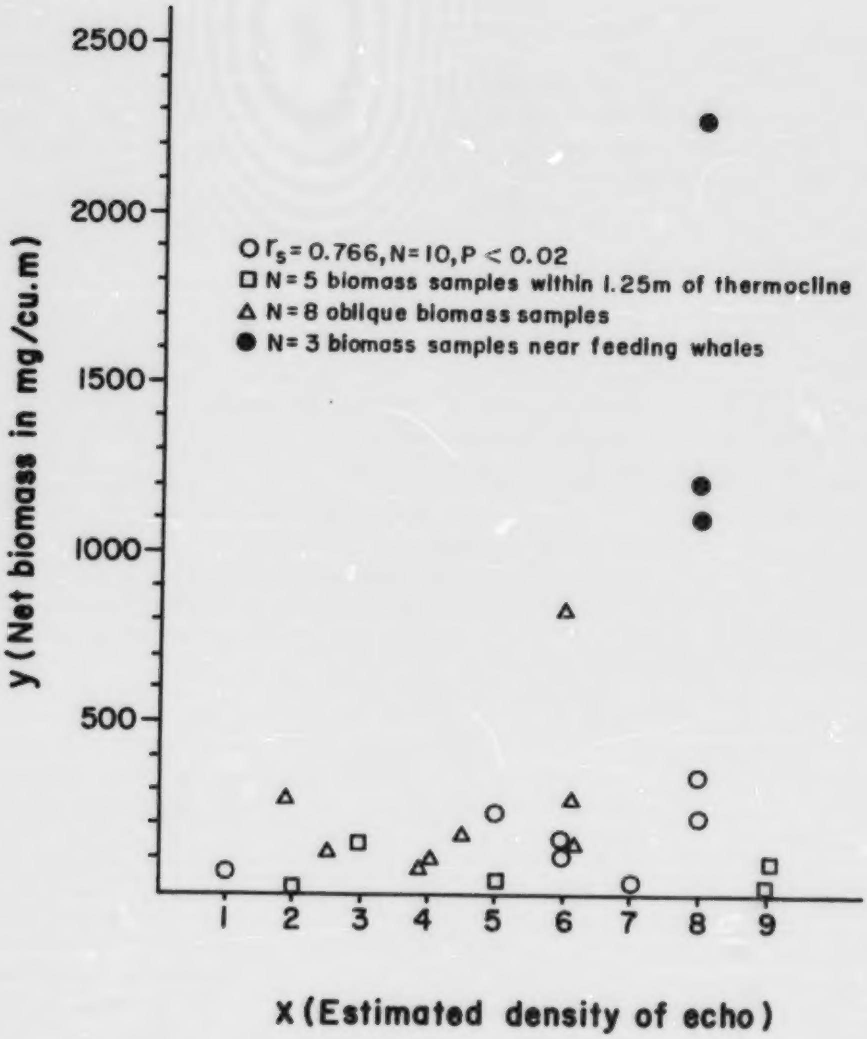


Figure 37. Correlation between net biomass and estimated density of echo registrations on sounder printout. Correlation is determined from horizontal samples collected more than 1.25 m away from the mid-thermocline depth (circles).

Thus it seems that visual classification of echo intensity on hydroacoustic printouts can be used to roughly estimate the biomass of zooplankton available in the water column, at least on an ordinal scale. We calculated the average biomass of zooplankton available in samples from three ranges of the 0-9 ordinal scale (0-4, 5-7 and 8-9). The resultant mean values (mg/m^3) were 147 (SD =80), 264 (SD = 263) and 1030 (SD = 832), respectively.

Three of the samples on which Figure 37 is based were collected in areas where bowhead whales were apparently feeding. Those three samples had both high biomasses of zooplankton and high densities of echo registrations. A mean biomass of 1030 mg/m^3 was found at locations where echo intensity was 8-9 on the ordinal scale. This value is near the theoretical threshold amount of zooplankton (1000 mg/m^3) required for economic foraging by bowheads, as determined by Thomson (1986). As a first approximation, echo densities coded as 8 or 9 may correspond to situations where feeding by bowhead whales would be economic.

Hydroacoustic surveys were conducted along parts of all five oceanographic transects that formed the sampling grid (Fig. 38). Only those portions of the hydroacoustic printouts that met two conditions were analyzed: the printouts had to be free of noise interference from the boat's depth sounder; and only those portions of the printouts with particular gain settings were utilized since comparability among transects was required. Visual assessment of standard markings (event markers) registered on the chart recorder showed no apparent changes in sensitivity during the study period, but this was a very rough means of assessing temporal variation in signal quality. Hydroacoustic gear that records the actual voltage returns of underwater targets would be a great improvement over the present gear; unfortunately, such gear was not available for this study. Nevertheless, we feel that printouts produced from the 200 kHz echosounder were useful in documenting the variation in zooplankton biomasses along the transects.

Relative zooplankton biomass as a function of depth and position along our transects was graphed for those portions of the transects that met the above criteria. For each 5 min (approximately 1200 m horizontally) by 1-m depth segment, the biomass was plotted as 0-4, 5-7 or 8-9 on our 0-9 ordinal scale (Figs. 39, 40). The position of the thermocline was determined at each sampling station and interpolated between stations. Apparent echo densities in segments within 1.25 m of the thermocline were not considered.

Most of the economically-profitable zooplankton biomass available to bowhead whales occurred near the thermocline, assuming that echo density 8-9 corresponds to profitable biomass. Only nearshore along transect 2 were profitable patches of zooplankton present near the bottom in shallow water. On transect 2, the maximum thickness of a patch of high density echo was 7 m, and perhaps 10 m if the patch continued upwards through the thermocline zone. Elsewhere, high-density patches were much thinner, generally from 1 to 3 m deep from top to bottom. The largest horizontal distance over which a high-density patch extended was 8.4 km. Other high-density patches varied in horizontal extent from <1 km to about 7 km. Although they did not occur on the transects, some patches appeared to be tens of kilometres in horizontal extent. Such patches were noted as we travelled between sampling stations and coastal anchorages.

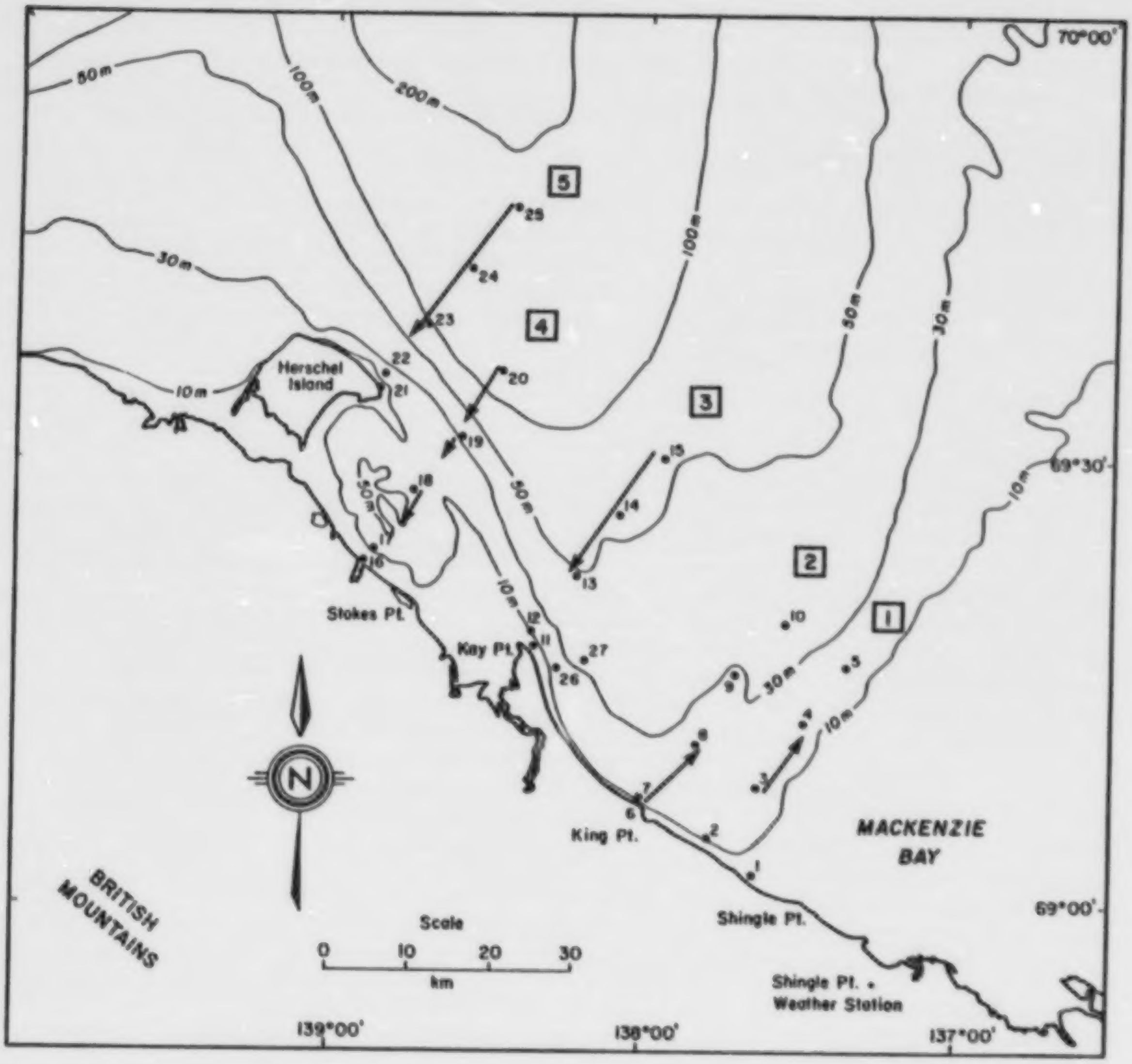

70°00'
69°30'
69°00'
139°00'
138°00'
137°00'
50m
100m
200m
30m
10m
Herschel Island
Stokes Pt.
Kay Pt.
King Pt.
Shingle Pt.
Shingle Pt. Weather Station
MACKENZIE BAY
BRITISH MOUNTAINS
N
Scale
0
10
20
30
km
1
2
3
4
5

Figure 38. Approximate locations of hydroacoustic surveys conducted along oceanographic transects off the Yukon coast in August 1985. Values in squares are transect numbers. Arrows indicate direction of travel.

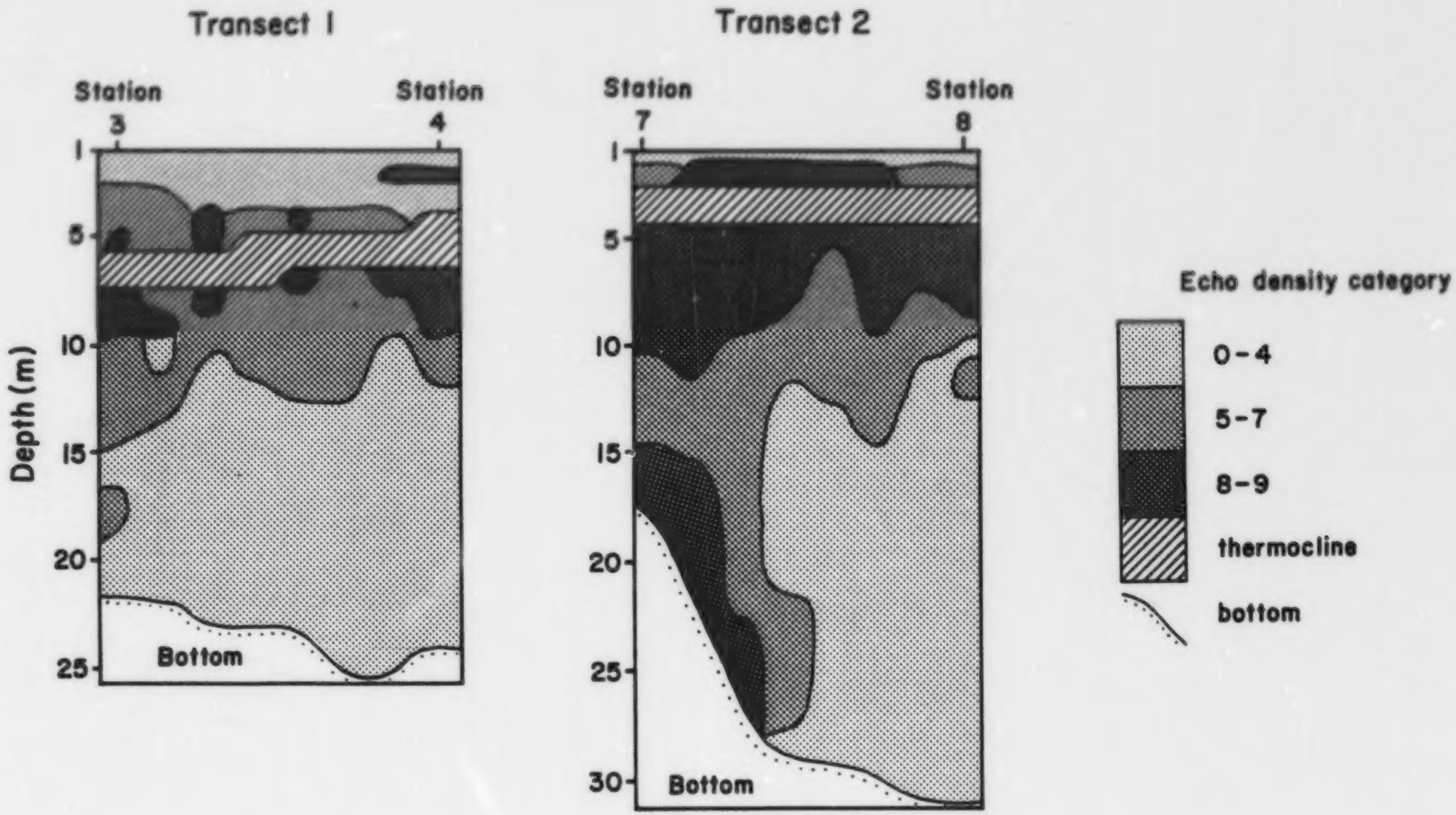


Figure 39. Distribution of hydroacoustic echo density along transects 1 and 2. For locations of transects, see Figure 38.

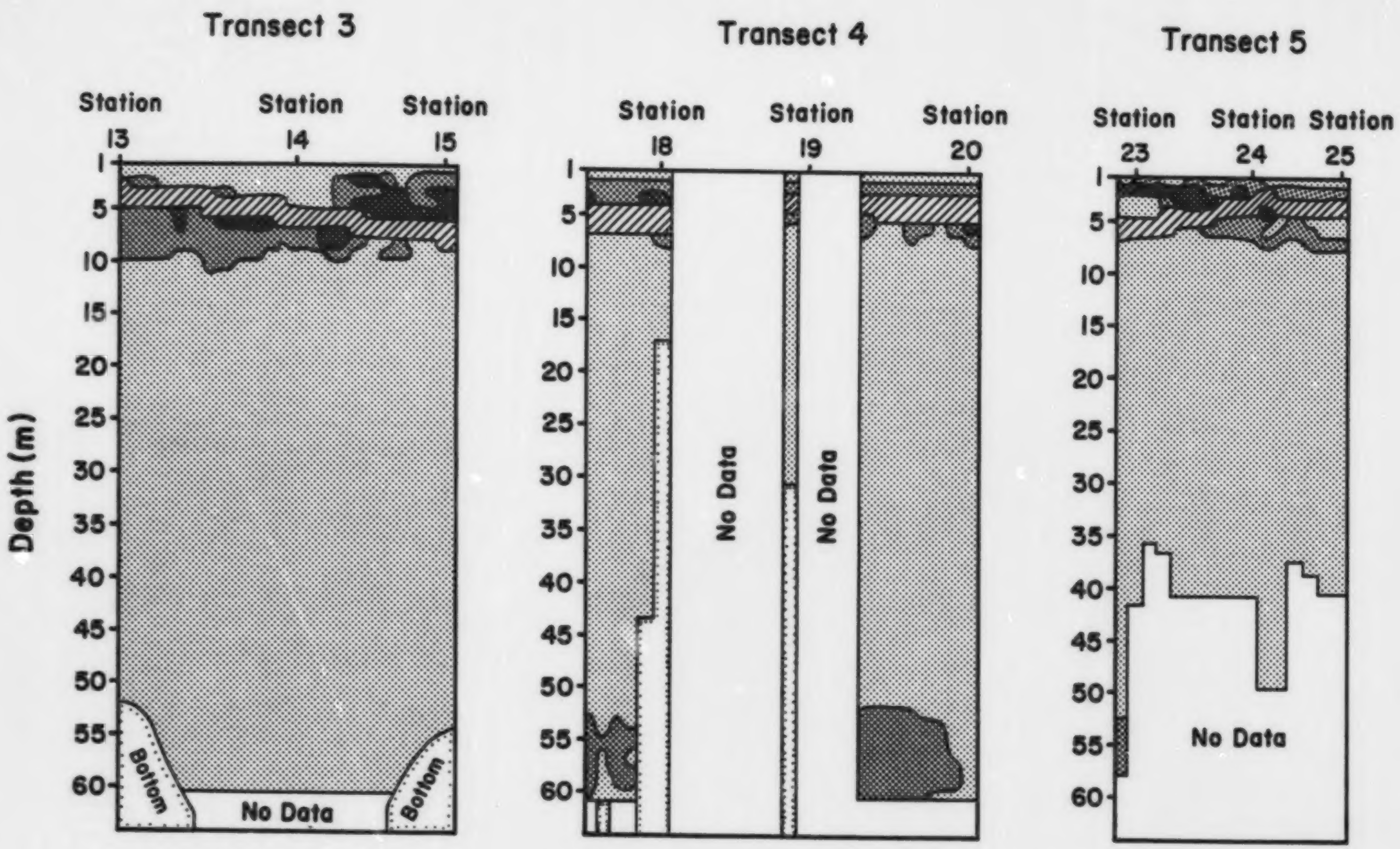


Figure 40. Distribution of hydroacoustic echo density along transects 3, 4 and 5. For locations of transects, see Figure 38. Legend as in Figure 39.

Segments with high echo densities were concentrated on transects 1 (9% of segments) and 2 (27% of segments), with far lower proportions on transects 3 (2%), 4 (0.5%) and 5 (2%) (Table 25).

Considering data from all transects, segments containing economically exploitable patches of zooplankton (echo densities of 8 or 9) occurred under 59% of the 70 1.2-km-long intervals sampled. Median ordinal estimates of echo were determined for each 1-m depth segment. When data from all depths were considered, median values indicated that echo, and presumably zooplankton biomass, was concentrated in the upper 10 m of the water column (Fig. 41).

Table 25. Frequency of occurrence of zooplankton biomass as estimated from hydroacoustic data in 5-min (approximately 1.2 km) by 1-m depth segments.*

Ordinal biomass category	Mean biomass (mg/m^3)	Transect 1		Transect 2		Transect 3		Transect 4		Transect 5		All transects	
		Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
0		1		1		411		17		9		439	
1		26		21		658		461		407		1573	
2		36		34		75		122		102		369	
3		25		18		26		40		34		143	
4		15		15		17		27		31		105	
(0–4)	147	107	66.5	89	46.4	1187	92.4	667	87.1	583	92.7	2629	86.8
5		11		11		14		45		13		94	
6		12		13		23		29		14		91	
7		16		27		33		21		8		105	
(5–7)	264	39	24.2	51	26.6	70	5.5	95	12.4	35	5.6	290	9.6
8		13		47		17		2		5		84	
9		2		5		10		2		6		25	
(8–9)	1030	15	9.3	52	27.1	27	2.1	4	.5	11	1.7	109	3.6

* Estimates of zooplankton abundance were determined visually from echo density on the hydroacoustic printouts.

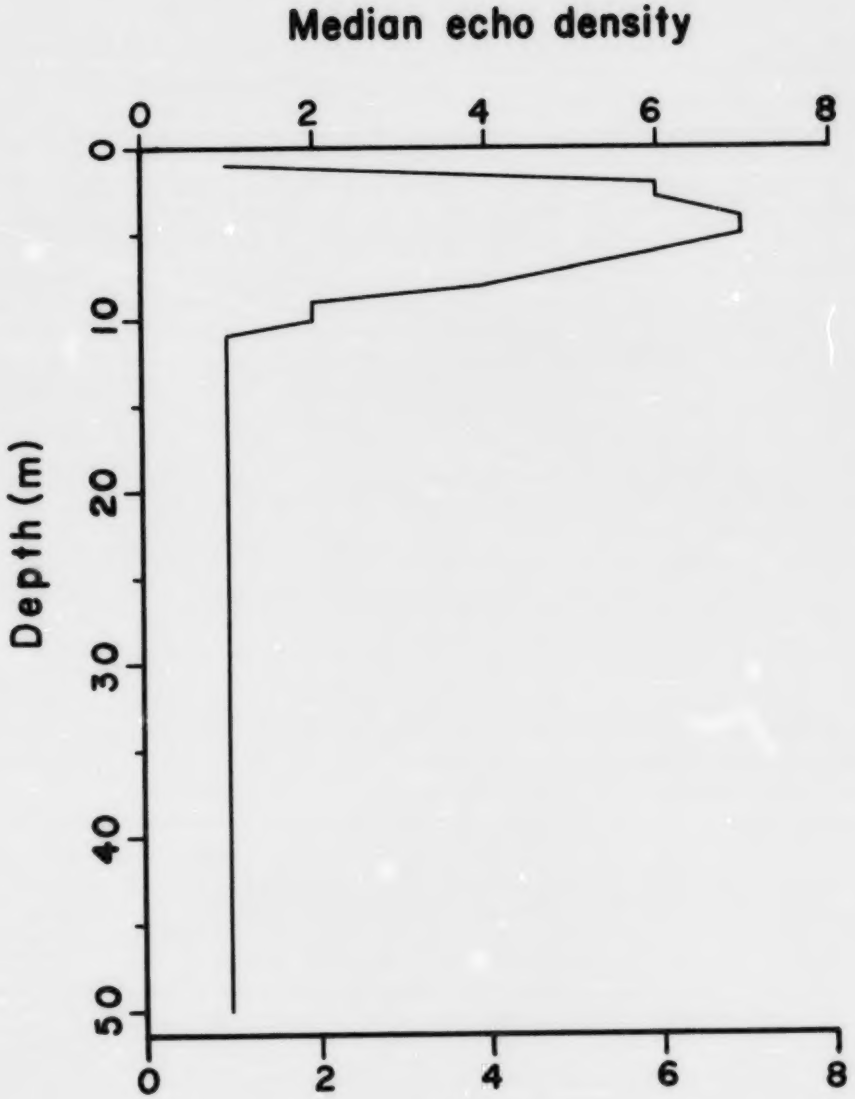


Figure 41. Distribution of median echo densities in 1-m depth intervals. Determined from all segments above the bottom (or 50 m) on transects 1 to 5. Segments within 1.25 m of the thermocline were not considered.

DISCUSSION

Bowhead whale use of the area of industrial activity north of the Mackenzie Delta has apparently declined since 1980 (Richardson et al. 1985, Norton and Harwood 1986). Two hypotheses have been advanced to explain this decline: (1) bowheads are now avoiding the industrial zone as a long-term behavioural response to noise and disturbance, and (2) bowhead distribution varies annually in response to natural variation in physical and biological oceanographic features that affect their food supply. It is important to note that these hypotheses are not mutually exclusive; both natural variations and behavioural avoidance can act simultaneously. The important point is that it is not possible to test the hypothesis that bowheads are avoiding the industrial zone until we understand how the whales respond to variations in the distribution of their food supply. This study was designed to provide such information; it is a response to recommendations made by the Beaufort Environmental Monitoring Project (ESL et al. 1985).

The following discussion is in four parts. In the first section, we make comparisons of the amounts of potential food (zooplankton and epibenthos) available to bowhead whales off the Yukon coast in August 1985 (this study), off the eastern Alaskan coast in September 1985 (Griffiths et al. 1986), and off Richards Island (outer Mackenzie Delta) in August 1980 (Griffiths and Buchanan 1982). We compare (1) composition of the zooplankton, (2) average biomasses in the water column, (3) biomasses in concentrated patches, and (4) energy potentially available in the zooplankton. We then discuss the life history of Limnocalanus macrurus, the dominant species in our 1985 samples, and compare the epibenthos available to bowhead whales in two of the three areas--off the Yukon coast and off Richards Island.

Following the section on food availability we discuss whale use of the study area in 1985, the theoretical energetic requirements of bowheads, and the species and sizes of zooplankters found near apparently feeding whales. We suggest that bowheads off the Yukon coast must have been feeding on very small zooplankters in 1985. The third section discusses the physical mechanisms that could concentrate such small prey into economically worthwhile aggregations and summarizes those features of the 1985 study area that, in concert, provided good feeding conditions for bowhead whales. The fourth section puts the results of the study in perspective with respect to current hypotheses attempting to explain the late summer distribution of bowhead whales in the Canadian Beaufort Sea.

Food Availability

In addition to the present study, two other studies have been specifically designed to gather information on the potential importance of zooplankton to bowhead whales. (1) Griffiths and Buchanan (1982) sampled zooplankton populations off the outer Mackenzie Delta in two years, using primarily vertical tows in 1980 and horizontal tows in 1981. Griffiths and Buchanan (1982) conducted 48 vertical zooplankton tows at eight stations off Richards Island in 1980. Mesh size on the plankton nets was 0.5 mm, similar to that used on our bongo tows. Tows taken by them near King Point were not considered since they used a different mesh-size than that employed near Richards Island and in our study. (2) Griffiths et al. (1986) used sampling gear identical to that employed herein to sample zooplankton in the eastern

Alaskan Beaufort Sea in September 1985. Those two studies, along with the present study, are the only investigations in which zooplankton biomass within the southern Beaufort Sea has been measured.

Since the best sources of data for general comparisons of zooplankton communities in the water column are oblique or vertical tows, only Griffiths and Buchanan's vertical tows, and not their horizontal tows, are used in the following comparisons. Their vertical tows were all in waters <40 m deep. In our study, oblique tows were made only through the upper 10-35 m of the water column, even though eight of the 16 tows were made at locations 52-171 m deep. Griffiths et al. (1986) made 12 oblique tows off the Alaskan coast between Kaktovik and Demarcation Point from 4 to 18 September 1985. These oblique tows, which sampled to a maximum depth of 100 m, were in nearshore (N = 1), inner shelf (N = 7) and outer shelf (N = 4) waters. The results from their tows in outer shelf waters (> 45 m deep) are not directly comparable with the results of the other two studies and are not considered below.

The following comparisons are based on data collected during the 14 August-18 September period.

Group and Species Composition in the Water Column.--The zooplankton community of arctic waters is generally, but not always, dominated by copepods (Hopkins 1969; Sekerak et al. 1976, 1979; Buchanan and Sekerak 1982). In the Beaufort Sea, Grainger and Grohe (1975) found that copepods contributed over 90% of zooplankton individuals in the Mackenzie Bay and Herschel Island area. Horner (1979, 1981) and Horner and Murphy (1985) found that copepods were the most common zooplankton offshore from the Alaskan coast, forming an average of 63% of numbers in fall and 88% in April-June. In this study, copepods formed 86.0% of zooplankton biomass and 99.1% of zooplankton numbers in the upper 10-35 m of the water column. By contrast, Griffiths and Buchanan (1982) found that copepods formed only 22% of total zooplankton biomass near Richards Island in 1980.

Three species of copepods (*Limnocalanus macrurus*, *Calanus hyperboreus* and *Calanus glacialis*) dominated the samples collected in our study area. The overall average biomass of *L. macrurus* (144.0 mg/m^3) was greater than that reported by Griffiths et al. (1986) from their nearshore and inner shelf samples off the Alaskan coast (53.9 mg/m^3), and much greater than that reported from samples taken in vertical tows near Richards Island in 1980 (<1 mg per sample; Griffiths and Buchanan 1982). However, *L. macrurus* was found to be common in horizontal tows taken near Richards Island in 1981 (Griffiths and Buchanan 1982).

In terms of biomass, *Calanus hyperboreus* was the second most important copepod in oblique tows in our study. The overall biomass of 15.4 mg/m^3 was far less than that found by Griffiths et al. (1986) in oblique tows conducted in nearshore and inner shelf waters of the Alaskan Beaufort Sea (79.7 mg/m^3). Likewise, Griffiths and Buchanan (1982) found that *C. hyperboreus* was generally the dominant species of copepod in vertical tows made off Richards Island (128.0 mg/m^3) in 1980.

Calanus glacialis ranked third in importance in the oblique tows made during this study. The overall biomass of 12.6 mg/m^3 was similar to that found by Griffiths and Buchanan (1982) off Richards Island in

1980 (mean of 10.6 mg/m^3). Griffiths et al. (1986) found somewhat higher biomasses of C. glacialis in their Alaskan samples (27.4 mg/^{3}).

Copepods accounted for 86% of the total biomass in the oblique tows made off the Yukon coast, 75% off the Alaskan coast, and only 22% off Richards Island (Table 26). However, absolute biomass of copepods was similar (181, 141, and 182 mg/m^3, respectively). In our study area, the small brackish-water copepod Limnocalanus macrurus was dominant, accounting for 68% of total zooplankton biomass, vs. 22% at corresponding depths off Alaska and <1% off Richards Island. The large copepods Calanus hyperboreus and Calanus glacialis accounted for only 13% of total zooplankton biomass off the Yukon coast vs. 22% off Richards Island and 44% off Alaska. The relative importance of copepods were similar in two study areas in 1985, and very different than those in the 1980 study area. While some of the 1985 vs. 1980 difference may be due to differing sampling methods, the difference is too large to be solely artifactual. Although copepods dominated the zooplankton in both the Yukon and Alaskan study areas in 1985, the dominant species were different. These results indicate that species composition of Beaufort Sea zooplankton can vary substantially from place to place and probably from year to year.

Although the samples collected during this study were overwhelmingly dominated by copepods, the other groups that occasionally formed important components of the zooplankton community (mysidacea, chaetognatha, hydrozoa, ctenophora, pisces, euphausiacea) have also been found to be important elsewhere in the Beaufort Sea (Table 26) and in the Arctic generally (Grainger 1965, 1975; Hopkins 1969; Sekerak et al. 1976, 1979; Horner 1979, 1981; Buchanan and Sekerak 1982; Griffiths and Buchanan 1982; Horner and Murphy 1985; Griffiths et al. 1986). Any of these groups may be locally abundant and were generally dominated by one or a few species.

Mysids, larval fish and chaetognaths occurred in similar amounts in the three areas listed in Table 26. On the other hand, samples collected off eastern Alaska had higher biomasses of euphausiids (10.5 mg/m^3) than did samples from the Canadian Beaufort Sea (<1-2.2 mg/m^3). Hydrozoans showed large variations in biomass between the three areas. Off Richards Island in 1980, hydrozoans were very abundant. Mean sample biomass of hydrozoans was 463.9 mg/m^3, of which 97% was Halitholus cirratus. In contrast, average hydrozoan biomass was much less in this study (4.1 mg/m^3). Although Griffiths et al. did not provide data specific to hydrozoans in their report, hydrozoans were also uncommon off eastern Alaska in September 1985 (Table 26).

In general terms, the group and species composition of the zooplankton community offshore from the Yukon coast is similar to that found elsewhere in the Beaufort Sea and elsewhere in arctic waters (Grainger 1965, 1975; Hopkins 1969; Grainger and Grohe 1975; Horner 1979, 1981; Griffiths and Buchanan 1982; Buchanan and Sekerak 1982; Horner and Murphy 1985; Griffiths et al. 1986).

Average Biomass in Water Column.--The average biomass found in our 16 oblique tows was 211 mg/m^3 (SD = 245, Fig. 42). This was similar to the average biomass found in eight oblique tows through waters <45 m deep off the Alaskan coast in September 1985 (244 mg/m^3, SD = 131, U = 41, P>0.1). The

Table 26. Dominant zooplankton (mg/m^3) in oblique and vertical tows in three areas of the Beaufort Sea.

	Off the Yukon coast August 1985	Off Richardson Island August 1980	Off eastern Alaska September 1985
	This study oblique tows (N = 16)	Griffiths and Buchanan (1982) vertical tows (N = 48)	Griffiths et al. (1986) oblique tows* (N = 8)
Copepoda	181.2	141.0	182.3
Limnocalanus macrurus	144.0	<1	53.9
Calanus hyperboreus	15.4	128.0	79.7
Calanus glacialis	12.6	10.6	27.4
Mysidacea	8.0	6.4	6.5
Mysis litoralis	7.8	<1	5.7
Euphausiacea	2.2	463.9	10.5
Thysanoessa raschii	1.8		8.5
Hydrozoa	4.1	19.1	
Ctenophora	4.9	-	
Aglantha digitale	3.3	-	9.6
Halitholus cirratus	.5	7.2	5.3
Mertensia ovum	.9	6.7	4.7
Beroe cucumis	1.2	6.7	?
Pisces	2.5	-	5.6
Chaetognatha	4.3	-	6.1
Sagitta elegans	3.2	-	5.0
Total zooplankton (including taxa not listed above)	210.7	631.7	244.1

* Transects 1, 2, and 4; stations 1, 2, 3, 7, 8, 11, 12, 13.

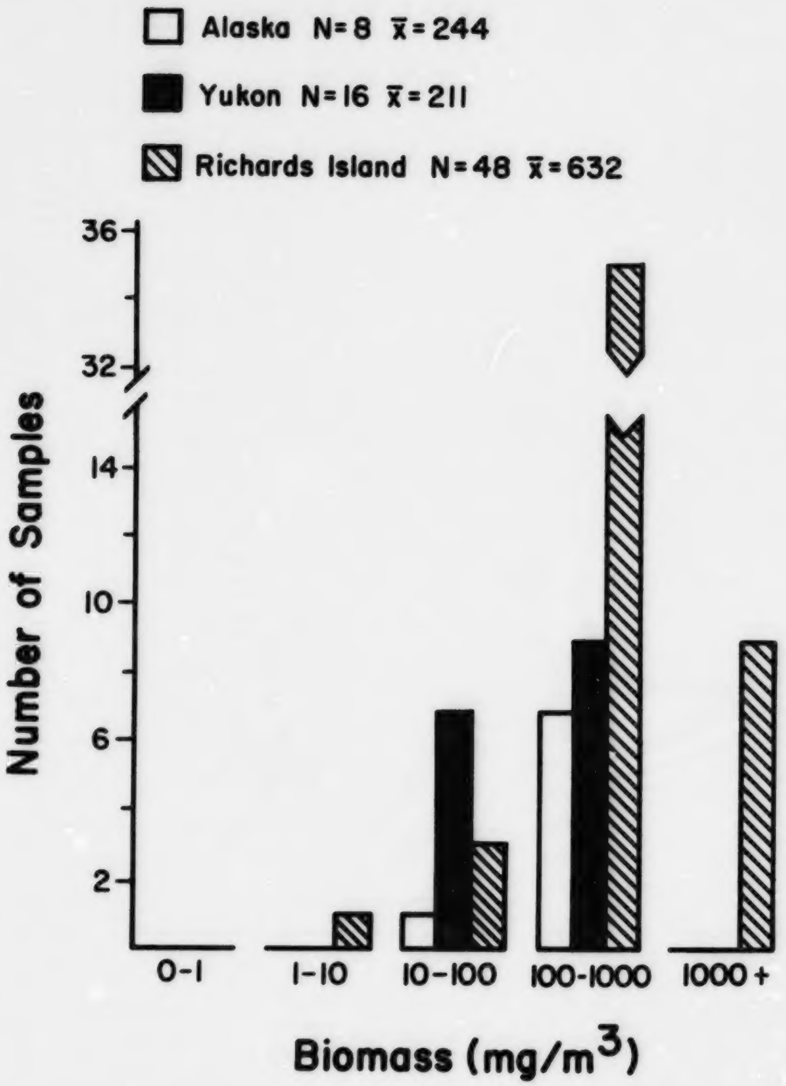


Figure 42. Distribution of zooplankton biomasses in oblique and vertical tows. Alaskan data from oblique tows through entire water column (Griffiths et al. 1986). Yukon data from oblique tows in upper 47% of water column. Richards Island data from vertical tows through entire water column (Griffiths and Buchanan 1982).

mean biomass at eight stations (48 vertical tows) near Richards Island in 1980 was 632 mg/m^3, which was significantly higher than that found in this study ($z = -3.66$, $P<0.01$). Much of the zooplankton biomass present in the vertical tows collected off Richards Island in 1980 consisted of hydrozoans (73.5%), a group that was uncommon in our oblique tows (2.2% of biomass, 0.4% of numbers, Table 5).

Thus, samples from the Canadian Beaufort Sea in 1980 contained a higher average biomass than those collected in 1985, although the study areas were not the same and the methods employed in the two years were not strictly comparable. Average biomasses off the Yukon and Alaskan coasts in 1985 were remarkably similar (Table 26).

Biomass in Zooplankton Concentrations.--Biomass in concentrations of zooplankton is likely to be of more relevance to feeding bowhead whales than is the average biomass of zooplankton available in the entire water column. At stations throughout the study area, we found that zooplankton biomass was much greater in certain thin layers than in the water column as a whole. We noted that zooplankton biomass in layers occurring at depth in diffuse plume water (mean of 71 mg/m^3) was much less than that in arctic waters (577 mg/m^3). Horizontal tows at the surface gave similar results: zooplankton biomass in diffuse plume waters (mean of 59 mg/m^3) was much lower than that in arctic water (889 mg/m^3).

Due to time constraints, we obtained most horizontal tows at depths where zooplankton was concentrated; few net samples were taken between the concentrated layers. In the Alaskan Beaufort Sea, however, Griffiths et al. (1986) found that zooplankton densities were indeed higher in layers, as defined by a 200 kHz echosounder, than in waters above or below those layers.

Griffiths et al. (1986) sampled apparent zooplankton patches both above and below the pycnocline in three water masses off the Alaskan coast in 1985. These water masses were defined as nearshore (<20 m), inner shelf (21-50 m) and outer shelf (51-200 m) waters. Griffiths et al. also sampled along a transect near the Yukon/Alaska border where a strong wind event had apparently mixed the surface layers and changed water mass characteristics.

In order to compare zooplankton abundances off the Alaskan and Yukon coasts, it is necessary to carefully control for the type of water being sampled. Results from both studies show great differences in the amounts of zooplankton present in waters with different properties. For comparative purposes, it is best to consider only those Alaskan data collected in known water masses. Waters above the pycnocline at inner shelf and outer shelf stations seemed to be variably influenced by Mackenzie plume waters and are generally comparable to the diffuse plume waters described in this study. Waters above the pycnocline at the single nearshore station sampled by Griffiths et al. were cold and are comparable to our arctic water data from above the thermocline. Waters below the pycnocline in Alaska seemed to be similar in water mass properties to our arctic waters below the thermocline. Griffiths et al. (1986) did not sample at the pycnocline, so any of our samples collected within 1.25 m of the thermocline have been excluded from the following comparisons. When information on the depth of the thermocline was not available in our study, data from horizontal tows at depth were not considered. At such stations, however, horizontal tows at the surface were considered to be above the thermocline.

Horizontal tows near the surface in waters influenced by the Mackenzie plume contained low zooplankton biomasses off both the Yukon coast (mean biomass of 56 mg/m^3) and Alaska (33 mg/m^3; $U = 17$, $P>0.1$; Fig. 43). Horizontal tows below the thermocline/pycnocline in arctic water revealed higher biomasses off both the Yukon coast (mean biomass of 602 mg/m^3) and Alaska (422 mg/m^3). Again, there were no differences between study areas ($U = 46$, $P>0.1$). Griffiths et al. (1986) sampled above the pycnocline in only one area of probable arctic water, and at that location water properties were probably affected by water movement out of a nearby coastal lagoon system. The biomass recorded in that one sample (131 mg/m^3) was much less than that in tows collected above the thermocline in arctic waters off the Yukon coast (mean biomass of 1165 mg/m^3; Fig. 43). In each of the three comparisons, biomass/m^3 was higher off the Yukon coast than off the Alaskan coast, but in no case was it significantly so.

When data from all horizontal tows are considered, nine of 41 horizontal tows off the Yukon coast contained >1000 mg/m^3, including two cases with 2142 and 2294 mg/m^3. By contrast, only one of 31 horizontal tows off Alaska had a biomass higher than 1000 mg/m^3; in that case the biomass was 1099 mg/m^3. High biomasses occurred more commonly off the Yukon coast than off Alaska.

In the Alaskan study area, Thomson (1986) suggested by modelling that 1000 mg/m^3 is the threshold for economic bowhead feeding. If this threshold is applicable to the Yukon study area, then echosounder data from the two areas also show that areas with high zooplankton biomass are relatively more common off the Yukon coast than off Alaska. In our study area, hydroacoustic segments roughly corresponding to biomasses >1000 mg/m^3 constituted 3.6% of all 1.2 km X 1-m segments ($N = 3028$) occurring on our transects. In Alaska, 0.2 km X 2 m segments representing zooplankton biomasses >1000 mg/m^3 constituted only 2.0% of the total ($N = 5263$). In our study area, segments with high biomass (echo density) occurred at one or more depths under 59% of the 1.2-km transect segments. In Alaska, similarly high biomass occurred under only 22% of the area surveyed (Richardson et al. 1986b).

Echosounder data from both the Yukon and the Alaska studies revealed that probable patches of zooplankton were thin (generally a few metres in thickness) but large in horizontal extent. Echosounder segments with high echo return were relatively more common on our eastern two transects (9-27%) than on our three western transects (0.5-2%). The largest probable patch of zooplankton occurring on our hydroacoustic surveys was at least 8.2 km long (Fig. 39). In Alaska, Griffiths et al. (1986) observed patches that were several kilometres in length. We observed layers of echo 10s of kilometres in length as we travelled between work stations and sheltered waters. These echoes probably represented zooplankton.

Energy Potentially Available in Zooplankton.--The energy available to bowhead whales off the Yukon coast in late August was consistently higher than amounts available off the eastern Alaskan coast in September (Table 27). This was in part a reflection of the greater amounts of zooplankton available in our study area. In addition, the mean unit energy value in our study area (1116 cal/g wet weight, $SD = 82$, $N = 38$) was significantly greater than that off Alaska (1003 cal/g wet weight, $SD = 213$, $N = 31$; $t = 2.78$, $P<0.01$). Varying sample composition probably accounted for this difference. However, it is also possible that over-wintering zooplankters (especially

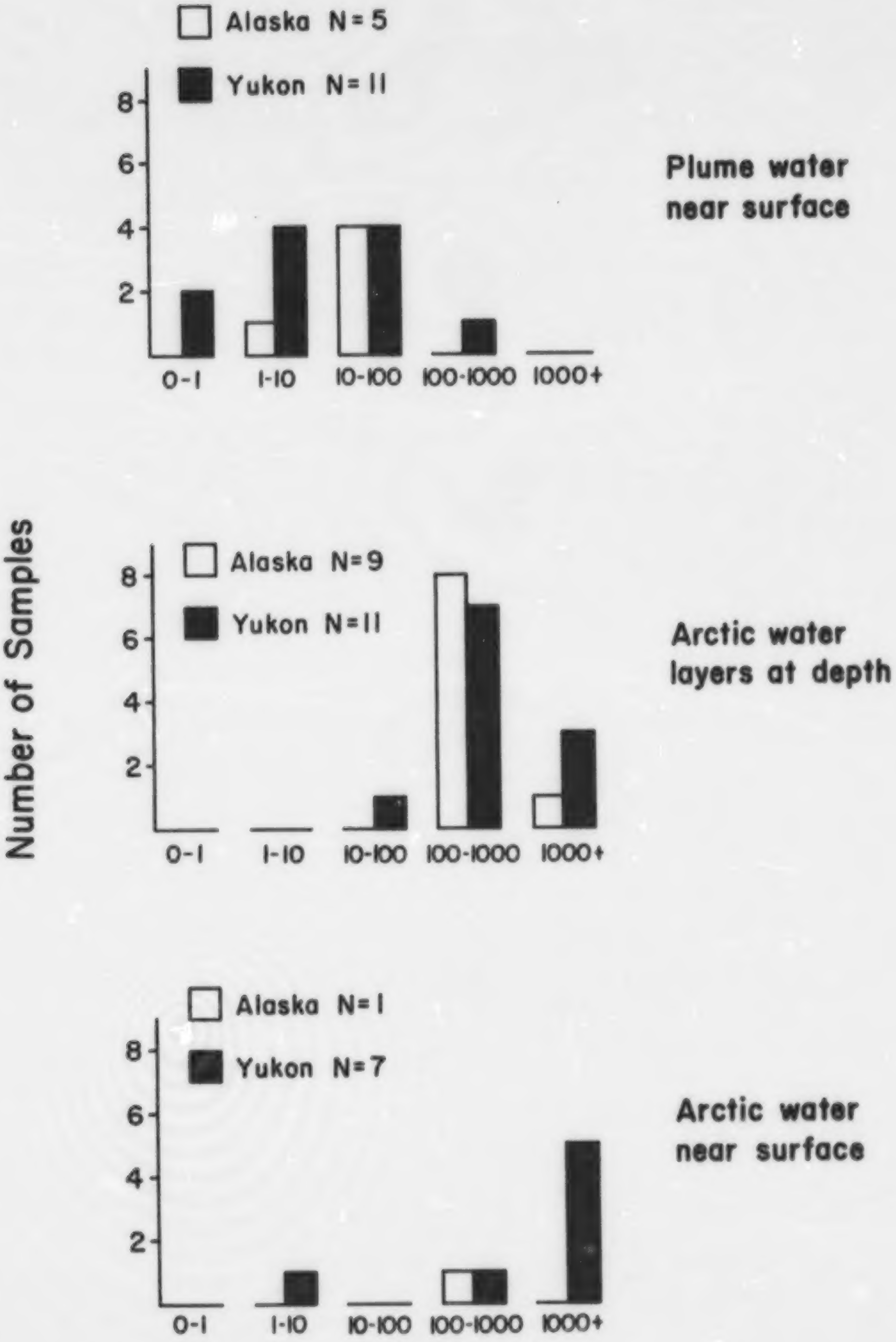


Figure 43. Distribution of zooplankton biomasses (mg/m^3) in horizontal tows. Alaskan data from Griffiths et al. (1986) excluding tows made in outer shelf waters.

Table 27. Estimated energy available to bowhead whales off the Alaskan and Yukon coasts in 1985.

Water mass	Sample type	Alaska*		Yukon**	
		cal/m^3	N	cal/m^3	N
Plume waters	near surface	30	5	223	4
Arctic waters	near surface	149	1	1011	11
	layers at depth	496	9	673	12
Water column	depth <45 m	265	8	306	11

* Adapted from Griffiths et al. (1986). Samples collected in September.

** This study. Samples collected in August.

copepods) that metabolize stored energy reserves during periods of food scarcity may have begun to do so at the time of the Alaskan collections (September).

Life History of Limnocalanus macrurus.--This small copepod dominated the biomass in our samples (Tables 5, 6, 9, 11 14 and 15). Limnocalanus macrurus has been reported from near-surface waters of the marginal seas of the Arctic Ocean (Grainger 1965). In the Beaufort Sea it is abundant wherever water of low salinity occurs (Grainger 1975; Grainger and Grohe 1975), and it is mainly restricted to nearshore shallow waters. Similar results have been obtained in the Alaskan Beaufort Sea (Horner 1981). Johnson (1956) found this species to have estuarine affinities, and suggested that its presence may indicate the spread of river water out over the ocean.

As already noted, Limnocalanus was not a major component of the total copepod biomass at any station in sampling conducted in 1980-81 near Richards Island and King Point (Griffiths and Buchanan 1982). Yet in the present study, Limnocalanus was, by far, the dominant component of zooplankton biomass. Off the Alaskan coast in September 1985, L. macrurus occurred in 34 of 43 samples, but its biomass was significant only at shallow stations on two of three transects (Griffiths et al. 1986).

The life history of Limnocalanus macrurus is poorly known, especially in marine waters. In Georgian Bay, Ontario, L. macrurus has a one-year life cycle, becoming adult in late spring but not spawning until autumn (Carter 1969). Carter found large numbers of adults until October but by December (freeze-up) the total number of adults had decreased greatly. L. macrurus females do not carry egg sacs; the eggs are extruded directly into the water, sink to the bottom, and hatch after a resting period of varying length (Hutchinson cited in Carter 1969). In Georgian Bay, the sex ratio of adults is 1:1. Naupliar and copepodite stages develop rapidly in spring, but L. macrurus then passes the summer in adult form without breeding.

Life-stage frequency distributions of L. macrurus collected in the Canadian and Alaskan Beaufort Seas are also consistent with a one-year life cycle: large numbers of adults are present in late summer and few other life stages are found at that time of year. In our study (late August), adult male and female L. macrurus were by far the dominant life stages collected in August (Fig. 35); only a few copepodite stages IV and V were enumerated. Off Alaska in September 1985, Griffiths et al. (1986) found that adults were also the dominant life stages; younger stages were found in only three of 43 samples. In coastal Alaskan waters in November, Horner and Murphy (1985) found moderate numbers of L. macrurus (1594-6017/m^3), but they found none in samples collected in March and April, even though small life stages of other copepods were captured.

The large numbers of adult stages of Limnocalanus macrurus present in the Beaufort Sea throughout the July-September period, the disappearance of younger life stages from July to September, and the spring absence of L. macrurus copepodites in areas where the species was moderately common the previous autumn, are all consistent with the life history of this species in Georgian Bay. These data strongly suggest that the species is monocyclic in the Beaufort Sea.

The energy values determined for small (<1.8 mm) copepods collected at nearshore locations and station 26 averaged 6785 calories per gram dry weight (Table 23). Given the composition of the samples analyzed (99.7% *Limnocalanus* by wet weight), this energy value can reasonably be considered as a first approximation of the energetic content of *Limnocalanus*. This value is less than that known for over-wintering calanoid copepods at this time of year (Lee 1974, 1975) but it would be ecologically consistent with a monocyclic strategy. If *L. macrurus* do not overwinter as adults, there would be no need for them to store exceptionally high levels of lipids. One would, however, expect breeding adults to contain considerable energy to cover the costs of reproduction and this probably accounts for the moderate energy values observed. Most of this energy was present as wax ester (lipid) in the samples analyzed (Table 24).

Epibenthos.--Griffiths and Buchanan (1982) collected eight epibenthic samples from two stations near King Point in August 1980. These samples were collected somewhat differently than the 28 samples we collected in the same general area in 1985. Our sampling gear sampled the water column on its descent from the surface, whereas the sampling device used by Griffiths and Buchanan was open at both ends and pursed when it struck the bottom. Therefore the results from the two studies are not strictly comparable. In Table 28, we have compared the biomasses of those taxa that are strongly associated with the bottom in shallow, nearshore waters: gammarid amphipods, mysids, euphausiids and isopods. Such taxa were probably sampled in roughly equivalent ways with the two types of sampling equipment.

In 1980 and 1985, total biomass of the four selected taxa was dominated by mysidacea and isopoda, but the rank order of these two taxa was reversed in the two years. This probably occurred due to the capture of large *Saduria entomon* in 1985 (total biomass of 10 items was 6.0 g) but not in 1980. Mysidacea were represented solely by *Mysis litoralis* in both years. Gammaridean amphipods collected in 1985 included *Apherusa glacialis*, *Onisimus glacialis* and unidentified oedicerotids. The mean biomass of the four epibenthic groups listed in Table 28 was apparently greater in 1985 than in 1980; however, because of the different techniques employed in the two years, the significance of the difference is unknown.

Whales in the Study Area

Many bowhead whales occurred in the area off the Yukon coast between Shingle Point and Herschel Island in 1983, 1984 and 1985, and in some years in the 1970s (Fraker and Bockstoce 1980; Richardson et al. 1985). Very few whales were along the Yukon coast between Shingle and Kay Points in 1980-82, although whales were found off Herschel Island in those years (Richardson et al. 1985).

Since bowheads are presumed to feed intensively in the late summer period (Lowry and Frost 1984; Thomson 1986), the distributions of zooplankton concentrations that are economic for bowhead whales to exploit are likely to affect the distributions of the whales themselves. In the late summer and early fall periods of 1985, large numbers of bowhead whales were present off the Yukon Coast. Bowhead whales occurring in this area were surveyed and photographed during our field study by the ESL/ESRF study (Norton and Harwood 1986; Cubbage and Calambokidis 1986) and by Davis et al. (1986).

Table 28. Group composition of selected epibenthic taxa in drop net samples from the vicinity of King Point, 1980 and 1985.

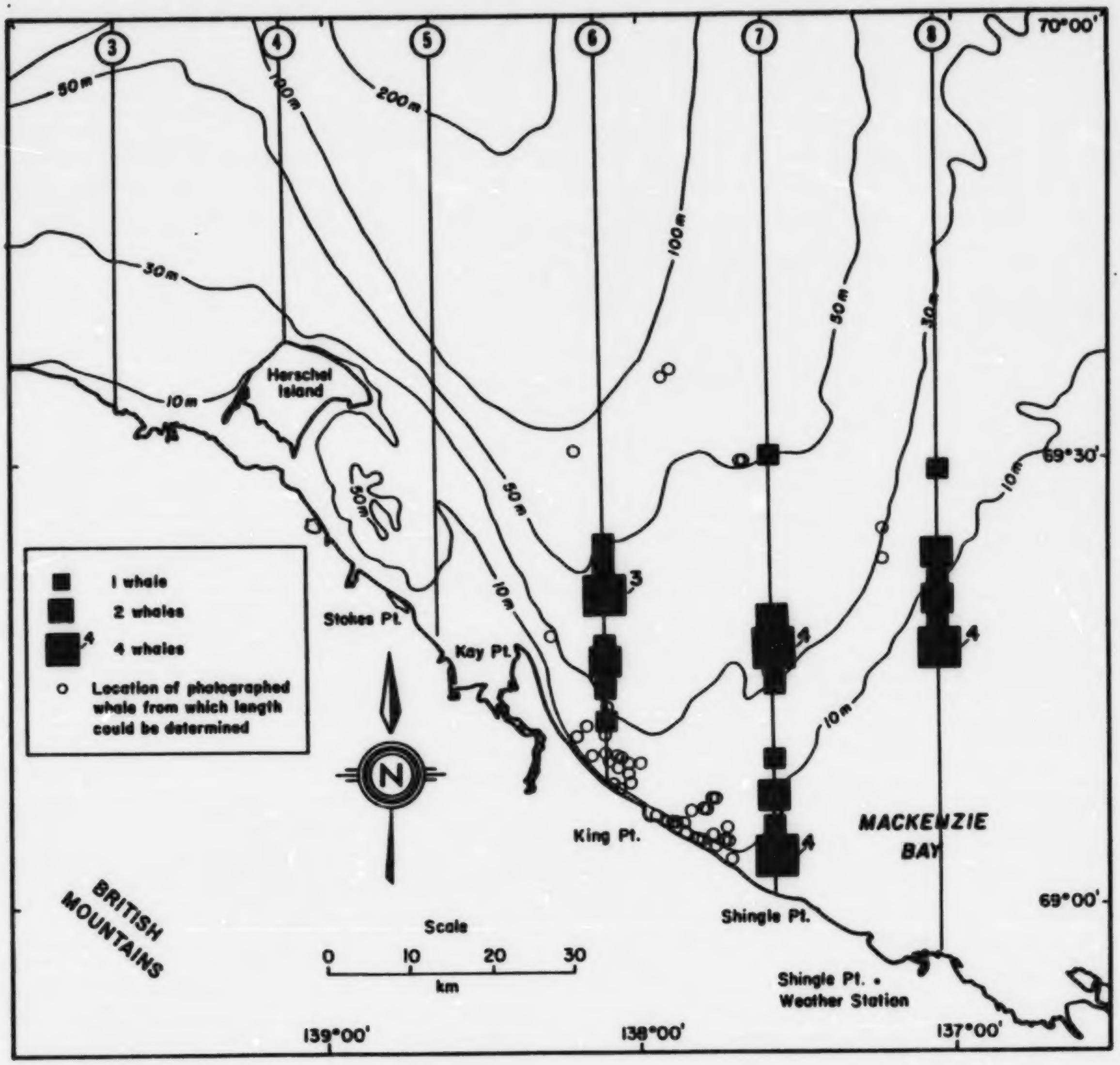
	Griffiths and Buchanan (1982) N = 8		This study N = 28	
	mg/m^2	%	mg/m^2	%
Gammaridea	7.6	.8	110.0	7.7
Mysidacea	634.0	72.9	255.0	17.8
Euphausiacea	7.2	.8	0.0	0.0
Isopoda	220.8	25.4	1069.0	74.6
Total	869.6		1434.0	

The distribution of whales in and near Mackenzie Bay, as determined by the ESL/ESRF study, is given in Fig. 44. The mean length of the 43 whales photographed in this area was 9.7 m (SD = 1.5). Based on the positions plotted in Fig. 44, the whales occurred over mean water depths of 26 m (SD = 20, range = 5-96 m, N = 72). Within this area there was no correlation between whale length and water depth (r = -0.17, N = 23, P>0.1), but the ranges of whale lengths and water depths included in this comparison were small.

Davis et al. (1986) obtained 241 photographs of measureable whales in and near our study area during 27-31 August 1985. The mean length of these whales was 9.5 m (SD = 1.5; Fig. 45). There was no significant difference in the mean lengths of whales in this area as determined by Cubbage and Calambokidis (1986) and Davis et al. (1986) (t = -0.83, P>0.1). Since adult bowhead whales are probably not less than 12.5-13 m in length (Davis et al. 1983, 1986; Cubbage et al. 1984; Nerini et al. 1984), most whales occurring off the Yukon coast in late August 1985 were immature animals (see also Fig. 14 in Cubbage and Calambokidis 1986). The whales photographed in this area by Davis et al. (1986) occurred over mean water depths of 21.1 m (SD = 21.2, range 4-140) and at a mean distance from shore of 7.2 km (SD = 5.8, range 4-140). Again, there was no correlation between whale length and water depth (r = 0.02).

In Alaska, Griffiths et al. (1986) showed that the biomass of zooplankton available to bowhead whales (between the pycnocline and the bottom or 50 m depth) decreased with increasing distance from shore. Our incomplete transect coverage precluded such analyses, but if we assume that the whales observed in the study area were feeding, then the distribution of the whales themselves is consistent with Griffiths et al.'s finding (see Fig. 44). We observed whales apparently feeding over shallow depths during this study. On 30 August 1985, Davis et al. (1986) estimated that there were about 500 bowheads in the King Point Block (see Figure 1b for the location of Davis et al.'s King Point Block). Biologists who were photographing the whales from the air on that day observed extensive feeding behaviour (mouths open, defecation at the surface, etc.; G. Miller, LGL Ltd., pers. comm.). Large numbers of whales (675 estimated) were again seen in the King Point Block on 6 September (Davis et al. 1986); these whales were feeding along a visible interface between turbid and clear water. On that occasion, MSWB observed echelon formations, whales swimming at the surface with their mouths open, and numbers of whales defecating at the surface. Whales remained in the King Point to Herschel Island area, in apparently diminishing numbers, until mid October in 1985 (C. Holdsworth, LGL Ltd., pers. comm.).

Energetic Requirements of Bowhead Whales.--Thomson (1986) has estimated the theoretical energetic requirements of bowhead whales in the Western Arctic stock. Based on Thomson's methods and assumptions, a bowhead 9.6 m in length (the average of estimates determined by Cubbage and Calambokidis 1986 and Davis et al. 1986), would require 488 kg of zooplankton each 20-h day during a 130-day feeding period (this assumes no winter feeding). Based on the relative frequencies of areas with various zooplankton biomasses in the eastern Alaskan Beaufort Sea in September 1985, such a whale would have to feed in areas with a mean zooplankton biomass of 1820 mg/m^3 and a minimum biomass of over 1000 mg/m^3 in order to meet its annual food requirements.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100m
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30m
10m
10m
Herschel Island
1 whale
2 whales
4 whales
Location of photographed whale from which length could be determined
3
4
4
4
4
Stokes Pt.
Kay Pt.
King Pt.
Shingle Pt.
Shingle Pt. • Weather Station
MACKENZIE BAY
BRITISH MOUNTAINS
N
Scale
0
10
20
30
km
139°00'
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137°00'

Figure 44. Locations of whales photographed and seen off the Yukon coast in late August, 1985 (after Cubbage and Calambokidis 1986 and Norton and Harwood 1986).

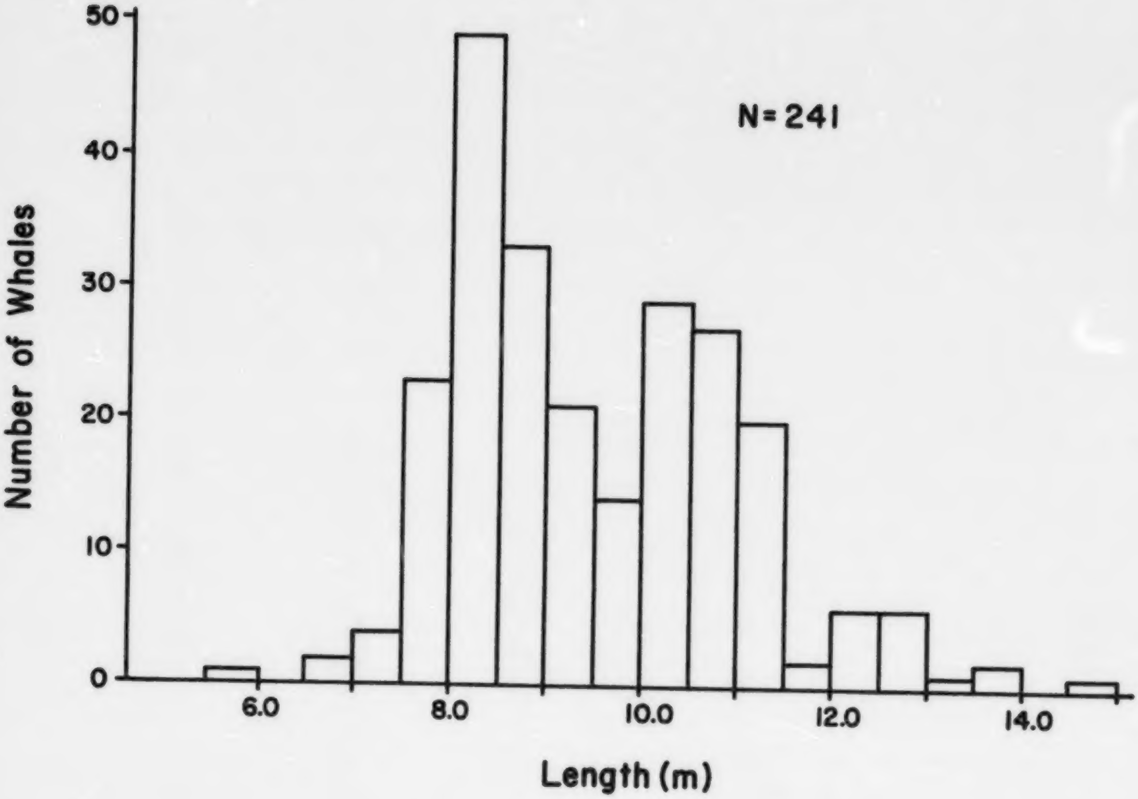

Figure 45. Length-frequency distributions of bowhead whales photographed offshore the Yukon coast 27-31 August, 1985. Adapted from Davis et al. (1986). Includes data from Herschel and King Point blocks.

If we assume that the above approaches are generally applicable to feeding off the Yukon coast, and if we further assume that high ordinal estimates of echo density on our hydroacoustic printouts represented areas with >1000 mg/m^3, then our echosounder surveys showed that 59% of our study area contained, at some depth, economically worthwhile patches of zooplankton.

Species and Sizes of Dominant Zooplankters near Feeding Whales.--Zooplankton samples were taken near apparently feeding whales at three stations. Limnocalanus macrurus, formed a relatively greater proportion of zooplankton biomass in presumed feeding samples than in presumed non-feeding samples (Tables 14 and 15). L. macrurus is a small copepod: mean adult cephalothorax lengths were 1.7 mm and 1.9 mm for males and females, respectively (Table 18).

Lowry and Frost (1984) found that the smallest items that were regular foods for bowheads were the copepods Metridia spp. (cephalothorax length 2.7-3.1 mm) and Calanus glacialis (2.4-3.3 mm). They noted that the smaller copepods Pseudocalanus (1.1-1.6 mm) and Derjuginia (1.4-1.8 mm), although very abundant in the Beaufort Sea, virtually never occurred in bowhead stomachs. (Pseudocalanus, approximately 1.3 mm in cephalothorax length, occurred in the stomach of one of eight bowheads harvested near Kaktovik; Lowry and Frost 1984.) They argued, therefore, that organisms smaller than about 2.5 mm were not effectively retained by bowhead baleen.

It is possible that the scarcity of small copepods in the bowhead stomach contents examined to date has reflected local scarcity of small copepods rather than an inability of bowheads to feed on small copepods. Griffiths et al. (1986) found Pseudocalanus to be rare in net samples from the Alaskan Beaufort Sea in September 1985. They found this species only in water depths <28 m. In our study Pseudocalanus was also rare, constituting only 1.0 mg/m^3 in our oblique tows. In contrast, Horner (1981) found Pseudocalanus to be abundant in eastern Alaskan waters during the autumns of 1977 and 1978, with females being common at nearshore stations. In 1978, Horner and Murphy (1985) found Pseudocalanus to be the numerically dominant copepod in Steffansson Sound, Alaska, but all their sampling was very near or inside the barrier islands in waters <10 m deep. Thus it seems that Pseudocalanus either exhibits large differences in annual abundance and/or is much more abundant in shallow waters than in deeper waters. The scarcity of Pseudocalanus in eight whale bowhead stomachs collected off Kaktovik is, therefore, not strong evidence that bowhead whale baleen cannot retain items <2.5 mm in length.

In our study area, Limnocalanus macrurus dominated the zooplankton community. It formed 68% of zooplankton biomass in oblique tows (Tables 5 and 6), 94% in horizontal tows near the surface (Table 9), and 78% in tows through suspected prey patches (Table 11). Almost all of the Limnocalanus captured were <2 mm in length (see Table 18 and Fig. 35).

Copepods <2 mm in length accounted for 75% of zooplankton biomass in horizontal tows through diffuse plume water and 86% of biomass in similar tows through arctic water (Fig. 46). If bowheads were not feeding on such small items, then it appears that it would have been impossible for them to feed efficiently in our study area. Given (1) the large numbers of whales

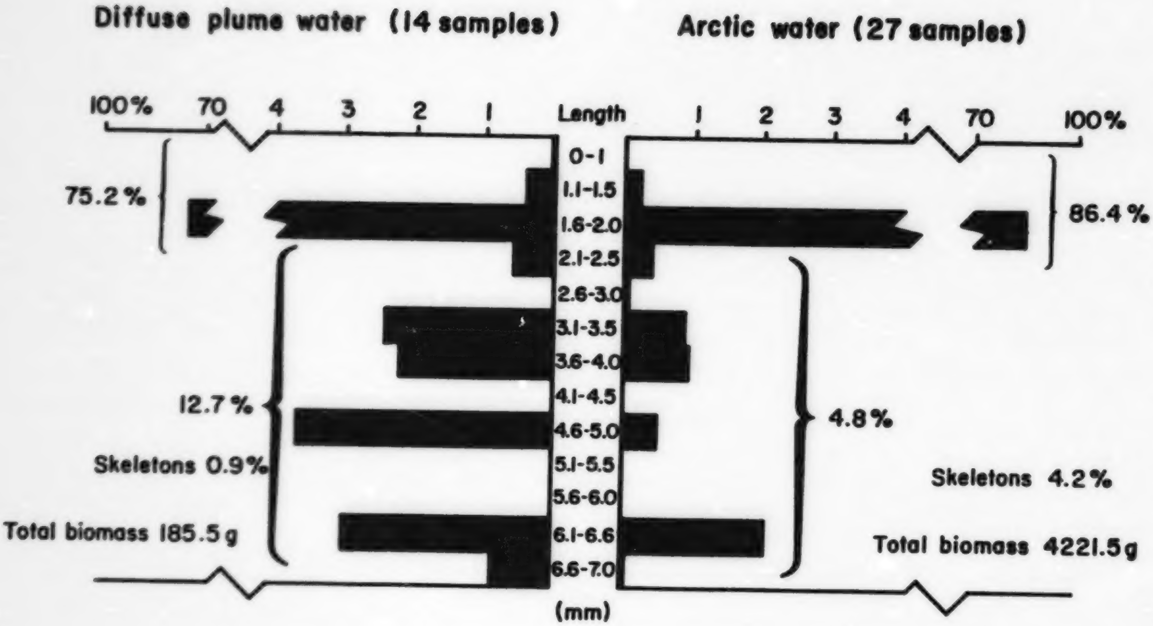

Figure 46. Length-frequency distributions of copepods in horizontal tows off the Yukon coast, August 1985. For each length interval the percentage contribution to total zooplankton biomass is given. The percentage weight of copepod skeletons is given separately.

present off the Yukon coast during the study period and, more generally, throughout the late summer and early fall of 1985, (2) their observed feeding activities, and (3) the predominance of small *Limnocalanus*, it seems necessary to conclude that in August 1985, bowhead whales were feeding on items <2 mm in length, and particularly on *Limnocalanus*.

Bowhead whales were observed feeding off Richards Island in 1980 and 1981. Griffiths and Buchanan (1982) conducted zooplankton tows near apparently feeding whales and in nearby areas where no bowheads were seen. Bowhead whales appeared to congregate in areas where copepod biomass was high in relation to that in other sampled areas.

Unlike the case in 1985, *Limnocalanus macrurus* was not an important component of biomass in samples collected at standard depths near apparently feeding whales in 1981; rather, larger calanoids, such as *Calanus hyperboreus* and *Calanus glacialis* dominated biomass. Hydrozoans, which constituted the major portion of the biomass in 1980 and were second to copepods in 1981, were of very little importance in our study area (2% of biomass in oblique tows, <0.5% in near surface tows, 0.3-1.0% in tows through suspected prey patches). Griffiths and Buchanan (1982) concluded that the presence of aggregations of copepods appeared to be the main factor influencing choice of feeding location, and our specific sampling in areas with apparently feeding whales and our general sampling in the study area support this finding.

Concentrating Mechanisms

The large scale distribution of surface water features in late August 1985 followed the usual patterns previously observed after periods of persistent easterly winds (Thomson et al. 1986). The plume of intensely turbid riverine water occupied the eastern portion of Mackenzie Bay, within the 20 m isobath. A broad, diffuse plume extended northwestwards past Herschel Island. Cold, clear arctic water was present at the surface in time-varying patches along the Yukon coastline between Shingle Point and Herschel Island, and west of Herschel Island.

The arctic water present at the surface along the Yukon coastline east of Herschel Island was probably the result of coastal upwelling driven by easterly winds. This tentative conclusion is based on the expansion of the area of arctic water from 20 to 28 August, as observed from the satellite imagery (Fig. 16 to 20), and the upward tilt toward the coastline of isotherms observed in some of the boat-derived vertical cross-sections (Fig. 25). Winds during this period were eastsoutheasterly, which would tend to move surface waters offshore, thereby inducing upwelling along the coast. It is possible that horizontal advection of cold clear water from west of Herschel Island may have also contributed (briefly) to the expansion of the area of arctic water within the study area from 20 to 28 August. Such an intrusion of cold water could have occurred during a period of westerly winds on 23 August.

The cold arctic water found along the Yukon coastline often occurred within comparatively small areas, typically measuring 5 km in the offshore direction by 10-15 km in the along-coastline direction. The locations of these upwelling areas changed considerably over periods as short as one to two days. From 20 to 28 August, they were most frequently observed off Kay

Point, as well as near Stokes Point and between King and Shingle points. The frequent changes in the surface distribution of cold arctic water was mirrored by complementary changes in the extent of diffuse plume water at the surface. Thus, the study area was characterized by constantly shifting planes of water with differing properties.

Under prevailing easterly winds, diffuse plume waters were advected into the study area from the east. But these same easterly winds, exacerbated at times by local and strong offshore (southwesterly) winds in the study area, probably also caused upwelling and displaced the diffuse plume waters. Satellite data suggest that frontal boundaries between these water masses had strong gradients over small horizontal distances.

Boat-derived data suggest that these surface fronts did not extend to great depth. Profiles of temperature and relative salinity (Fig. 22) indicate that, at many stations in the study area, a thin layer of warm, relatively fresh water covered colder, denser arctic water. This would be consistent with the spread of fresh Mackenzie River water out over the ocean. If *Limnocalanus*, a known brackish-water copepod species, is highly associated with diffuse plume water, then the surficial displacement of diffuse plume water by upwelled arctic water could serve to further concentrate this zooplankter.

In our study area, zooplankton patches representing economically profitable congregations of zooplankton were apparently concentrated around the thermocline (Fig. 39 and 40). Patches tended to be fairly thin but extensive horizontally and were generally found in the upper 10 m of the water column (Fig. 41), as was the thermocline (Table 4). At four stations where zooplankton samples were taken near apparently feeding whales, patches of zooplankton (as determined from echosounder and net sampling) occurred at or just below the thermocline (Fig. 20, 31 and 32). Net sampling revealed that most zooplankton biomass in these samples consisted of *Limnocalanus macrurus*. Horizontal tows revealed that biomasses were higher in arctic waters than in diffuse plume waters by about an order of magnitude (Tables 8 and 11). It was also evident that *L. macrurus* was dominant in these tows (Tables 9 and 12). The sample with the highest biomass observed during this study (2.3 g/m^3) was collected just below the thermocline at station 26, an apparent whale feeding location. Interestingly, in this sample copepod skeletons formed 11% of sample biomass. Since copepod skeletons normally sink to the bottom, this is another indication that zooplankton were being concentrated by a strong density gradient (Fig. 20).

The most intense frontal features near the Yukon coastline, at least over scales of 1-2 km or greater, were near Kay Point, and, less frequently, between King Point and Shingle Point (Fig. 21). Many bowhead whales occurred in this area in the late summer and early fall of 1986 (Davis et al. 1986). The strong fronts occurred within 5-20 km of the shore and generally separated arctic water found adjacent to the coastline from the warm, turbid waters of the intense Mackenzie River plume. Along these fronts, there would appear to be a considerable potential for aggregation of zooplankton through physical mechanisms associated with frontal features (Parsons and Takahashi 1973). The driving force behind the presence/absence of these fronts off the Yukon coast seems to be local and regional meteorological events.

Bowhead whales occurred in numbers near the Yukon coast in 1983-1985 and in some years in the 1970s (Fraker and Bockstoce 1980; Richardson et al. 1985; Cubbage and Calambokidis 1986; Davis et al. 1986; Norton and Harwood 1986). At least in 1983-85, it appears that these concentrations of whales occurred in an area of strong frontal features in the area (this study, Borstad 1985; Harwood and Borstad 1985). One could hypothesize that the occurrence of such whale concentrations is dependent on yearly hydrometeorological events. Following prolonged periods (>2 weeks) of easterly winds during August, bowhead whales will occur along the Yukon coast. In years with prevalent westerlies or no strong winds during August, bowheads will not occur in large numbers in this area. Studies of zooplankton and bowheads conducted in 1980 and 1981 are consistent with these predictions. In those years, prevalent August winds were westerly (see Figs. 13, 15 and 16 in Thomson et al. 1986), and few bowhead whales occurred in the study area (Richardson et al. 1985). Bowheads were, however, observed off Richards Island in those years and zooplankton sampling indicated that concentrations of typical arctic copepods (Calanus hyperboreus and C. glacialis) and not L. macrurus were the main factor affecting choice of feeding locations.

Bowhead whales probably feed on any species of zooplankton sufficiently concentrated to provide a reasonable energy return. The specific taxa on which bowhead whales feed may be affected by the unit energy values of the food taxa available and on the concentrating mechanisms at work in a given situation. The ability to capitalize on local concentrations of suitable food would be highly adaptive in an animal whose energy requirements are high relative to average food concentration.

Summary and Implications

The hydrographic regime occurring off the Yukon coast in late summers with prevailing easterly winds is conducive to the formation of zooplankton concentrations. Zooplankton concentrations of high biomass were found off the Yukon coast during this study. Zooplankton biomass was >1 g/m^3 in nine of 41 horizontal tows. Echosounding equipment showed that, in 59% of the area, patches with zooplankton biomasses roughly estimated as >1 g/m^3 occurred at some depth. Large numbers of whales occurred in the study area. Near one group of apparently feeding whales, zooplankton biomass was 2.3 g/m^3. The small copepod Limnocalanus macrurus was dominant in the zooplankton, and this species and other copepods <2 mm in length represented 75-86% of zooplankton biomass. There is strong evidence that bowhead whales must have been feeding on these very small items.

In contrast, fewer than usual numbers of bowhead whales were found feeding off the eastern Alaskan coast in September 1985 where only one of 31 samples and 22% of the area contained zooplankton biomasses >1 g/m^3. It seems that the Yukon coastal area offered better feeding opportunities in 1985 than did the area off Alaska. However, only a fraction of the bowhead population was present along the Yukon coast; the whales present there were mainly yearlings and other subadults.

The results of the 1985 studies and of a 1980 study near Richards Island, are consistent with the hypothesis that locations with high zooplankton biomass vary from year to year, probably depending on regional and local meteorological events. The results also suggest that dominant species in the zooplankton are also variable. However, to fully evaluate the hypothesis that bowhead distribution varies in response to changes in the distribution of their food, we need information on zooplankton availability along the Yukon coast in years with prevailing westerly winds during late summer. We also need directly comparable, near-simultaneous information on food availability along the Yukon coast and in the zone of industrial activity. Ideally, we need information from both areas in a year with prevailing westerly winds and, again, in a year with easterly winds.

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Appendix 1. Biomass (mg) of major groups of zooplankton per cubic metre of water filtered.

Date in August 1985		23	23	23	23	23	23	25	25	25	25
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal		1	1	1	2	1	3	1	1	1	1
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m		1	1	1	6	2	1	1	1	1	2
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water		2	2	1	1	1	1	1	1	2	2
Depth of thermocline (m)		4	3.5	6.25	6.25	3	4	4.5	4.5	4	5.5
Secchi depth (m)		4	3.7	3.4	3.4	3.1	1.8	1.4	1.4	2.3	3.4
Water depth (m)		171	157	81	81	12	6.5	131	131	39	17
	Sample number	1	2	3	4	5	6	7	9	10	11
Taxon	Cu. m filtered	90.12	111.42	102.19	191.28	56.06	198.37	12.62	18.47	132.72	81.35
All Zooplankton		79.317	41.303	56.248	252.515	79.463	14.283	40.990	123.698	78.647	774.432
All Hydrozoa		4.494	.072	2.368	.596	.089	0.000	1.109	12.453	8.597	3.540
All Ctenophora		9.898	.547	.362	3.555	0.000	.056	0.000	19.437	.799	.897
All Pteropoda		.177	.215	.157	.037	.143	0.000	.396	.758	.829	2.643
All Chaetognatha		8.190	7.458	5.098	.486	1.855	.181	5.626	10.883	2.072	2.557
All Larvaceans		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Pisces		.377	4.021	1.331	3.607	.642	0.000	0.000	.650	0.000	.283
All Ostracoda		0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Mysidacea		.056	2.028	.069	0.000	1.677	0.000	0.000	.217	.467	5.925
All Euphausiacea		0.000	0.000	0.000	.172	0.000	0.000	0.000	0.000	.490	1.954
All Decapoda		.133	.323	.930	.972	0.000	0.000	3.090	1.624	.618	2.397
All Calanoida		53.884	25.624	44.398	224.629	73.541	13.991	28.629	74.320	60.277	749.982
All Hyperiidae		.777	1.014	1.536	16.599	1.213	0.000	1.268	2.978	2.449	1.377
All Gammaridae		.977	0.000	0.000	.523	.303	.056	0.000	0.000	1.808	2.090
All Echinoderms		0.000	0.000	0.000	0.000	0.000	0.000	.079	0.000	0.000	0.000
All Isopoda		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Hydroids		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1 (continued).

Date in August 1985		25	25	26	26	27	27	27	27	27	27
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal		3	3	3	3	1	3	2	3	2	3
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m		1	1	1	1	1	1	4.2	8	7.9	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water		3	3	3	3	1	1	1	1	1	1
Depth of thermocline (m)		5.5	9	0	0	7.5	7.5	7.5	7.5	5.75	5.75
Secchi depth (m)		2	.8	1.5	1.5	.9	.9	.9	.9	.9	.9
Water depth (m)		11	8	11	7	57	57	57	57	64	64
	Sample number	12	13	14	15	16	17	18	19	20	22
Taxon	Cu. m filtered	220.11	211.95	230.18	218.19	181.64	202.02	221.55	214.65	263.03	207.74
All Zooplankton		443.792	1275.183	360.870	556.313	126.767	.613	39.358	152.686	1097.745	1.217
All Hydrozoa		1.940	4.728	2.859	1.114	2.070	0.000	0.000	2.143	3.270	0.000
All Ctenophora		.940	4.124	.495	.445	.562	0.000	0.000	.117	2.296	0.000
All Pteropoda		.086	5.638	.295	.142	.072	0.000	0.000	0.000	.023	0.000
All Chaetognatha		.045	.722	2.190	2.732	4.327	0.000	0.000	1.216	.164	0.000
All Larvaceans		.018	.024	.004	.009	0.000	0.000	0.000	0.000	0.000	0.000
All Pisces		0.000	6.181	1.377	4.922	4.724	0.000	0.000	17.657	20.378	0.000
All Ostracoda		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Mysidacea		.032	.623	0.000	.032	1.657	0.000	0.000	1.994	20.929	0.000
All Euphausiacea		0.000	0.000	0.000	0.000	1.800	0.000	0.000	0.000	0.000	0.000
All Decapoda		0.000	.193	0.000	0.000	2.477	0.000	0.000	9.411	12.261	0.000
All Calanoida		434.555	1250.177	352.780	545.717	108.330	.569	39.358	119.003	1038.250	.991
All Hyperiidae		.054	.274	0.000	.422	.517	0.000	0.000	.848	.175	0.000
All Gammaridae		4.957	.085	.313	.770	0.000	0.000	0.000	.149	0.000	0.000
All Echinoderms		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Isopoda		0.000	0.000	0.000	0.000	.231	0.000	0.000	0.000	0.000	0.000
All Hydroids		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1 (continued).

Date in August 1985	27	27	27	27	27	28	28	28	28	28
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	2	1	1	3	2	3	3	3	3	2
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	21.1	1	1	1	6.5	1	1	1	1	7.7
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	1	1	1	1	1	3	3	3	3	3
Depth of thermocline (m)	5.75	5.75	3.5	3.5	3.5	9	9	9	9	9
Secchi depth (m)	.9	.9	1.2	1.2	1.2	2.3	2.1	1.4	2.3	2.3
Water depth (m)	64	64	52	52	52	8	12	6.5	11.7	11.7
Sample number	23	24	25	26	27	28	29	30	31	32
Taxon Cu. m filtered	452.9	185.89	242.86	210.52	187.45	223.543	205.16	219.48	213.29	209.85
All Zooplankton	125.920	287.557	91.452	1.181	752.809	1138.712	1362.332	1795.043	2141.990	1399.180
All Hydrozoa	3.985	1.877	2.952	0.000	9.864	1.440	5.230	.948	15.041	16.345
All Ctenophora	.117	3.717	0.000	0.000	6.247	0.000	3.636	.027	2.096	1.101
All Pteropoda	0.000	.140	.008	0.000	4.172	0.000	0.000	0.000	0.000	0.000
All Chaetognatha	3.983	2.141	0.000	.009	2.918	5.359	6.088	9.158	15.036	25.718
All Larvaceans	0.000	0.000	0.000	0.000	0.000	.004	0.000	.009	.005	.009
All Pisces	4.659	2.012	0.000	0.000	1.750	.300	0.000	0.000	0.000	.901
All Ostracoda	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Mysidacea	1.574	4.530	.206	0.000	7.063	6.012	0.000	.396	0.000	16.216
All Euphausiacea	6.045	2.776	0.000	0.000	.416	0.000	0.000	0.000	0.000	.772
All Decapoda	.188	.995	.103	0.000	.240	.004	0.000	.068	0.000	.410
All Calanoida	100.283	265.668	86.264	.949	704.700	1125.059	1347.129	1782.673	2109.063	1330.717
All Hyperiidae	2.025	.495	.017	.005	10.835	.089	.102	.237	.258	2.335
All Gammaridae	.093	.108	.008	0.000	.507	.349	.146	.328	.202	2.216
All Echinoderms	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Isopoda	0.000	0.000	0.000	0.000	0.000	.094	0.000	0.000	0.000	0.000
All Hydroids	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1 (continued).

Date in August 1985	29	29	29	29	29	29	29	29	29	29
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	2	3	3	3	2	3	2	2	1	3
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	8.3	1	1	8.3	7.1	1	9.3	23.4	1	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	3	3	3	3	3	3	3	3	3	1
Depth of thermocline (m)	1	4	6	5	9	9	9	9	9	7.25
Secchi depth (m)	7.5	2.5	12	12	5.2	10.5	10.5	10.5	10.5	1.5
Water depth (m)	25	25	34	34	11	31	31	31	31	21
Sample number	33	34	35	36	37	38	39	40	41	42
Taxon Cu. m filtered	220.86	227.97	212.63	213.64	201.22	222.58	205.04	342.69	216.52	221.56
All Zooplankton	2294.309	692.600	8.833	166.912	811.236	1.165	131.433	167.341	170.003	448.642
All Hydrozoa	3.495	.759	3.758	7.232	13.383	0.000	.824	12.886	9.163	.551
All Ctenophora	.082	.316	.847	1.498	.512	0.000	.912	1.068	10.105	0.000
All Pteropoda	.697	1.742	.005	1.999	3.350	.148	5.311	1.100	3.884	.086
All Chaetognatha	6.280	.759	0.000	.913	3.827	0.000	.897	3.268	2.217	.122
All Larvaceans	.036	0.000	.005	0.000	.005	0.000	0.000	.006	0.000	0.000
All Pisces	1.213	.197	0.000	0.000	.050	0.000	2.117	0.000	0.000	.907
All Ostracoda	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Mysidacea	26.315	.412	0.000	.440	3.196	0.000	.493	.505	1.219	1.512
All Euphausiacea	1.635	0.000	0.000	.061	2.485	0.000	.180	22.443	11.126	0.000
All Decapoda	1.023	0.000	0.000	.009	.055	0.000	1.824	.198	.319	.113
All Calanoida	2251.675	688.231	3.918	153.206	781.120	.801	116.841	121.594	127.540	444.701
All Hyperiidae	1.376	0.000	0.000	.094	3.071	0.000	1.419	1.471	2.360	0.000
All Gammaridae	.480	.184	.019	.187	.184	.135	.302	1.118	2.069	0.000
All Echinoderms	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Isopoda	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Hydroids	0.000	0.000	0.000	0.000	0.000	0.000	.156	0.000	0.000	0.000

Appendix 1 (continued).

Date in August 1985	29	29	30	30	30	30	30	30	30	30
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	1	2	3	2	2	2	3	2	1	3
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	2	8.6	1	4.4	8.3	18.1	1	8.3	1	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	1	1	1	1	1	1	1	1	1	1
Depth of thermocline (m)	7.25	7.25	5.25	5.25	5.25	5.25	3	3	3	6.25
Secchi depth (m)	1.5	1.5	1.7	1.7	1.7	1.7	1.8	1.8	1.8	2.6
Water depth (m)	21	21	21	21	21	21	34	34	34	21
Sample number	43	44	45	46	47	48	49	50	51	52
Taxon Cu. m filtered	65.63	246.26	183.99	197.91	221.15	258.44	194.36	192.79	175.75	213.92
All Zooplankton	836.325	1202.960	2.544	10.643	335.415	216.859	62.230	157.233	193.036	.345
All Hydrozoa	1.204	.528	.049	0.000	1.632	6.446	0.000	.353	1.132	0.000
All Ctenophora	.289	.162	0.000	0.000	7.511	1.006	.880	1.603	.410	0.000
All Pteropoda	1.859	2.753	.005	0.000	1.198	.267	.098	.213	.512	0.000
All Chaetognatha	1.371	1.450	0.000	0.000	3.156	3.266	0.000	.617	10.225	0.000
All Larvaceans	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.011	0.000
All Pisces	3.870	2.680	.859	10.308	10.056	21.084	0.000	2.951	.450	0.000
All Ostracoda	0.000	0.000	0.000	0.000	0.000	.252	0.000	0.000	0.000	0.000
All Mysidacea	38.504	19.963	0.000	0.000	10.292	17.145	11.587	4.212	14.128	0.000
All Euphausiacea	1.127	.321	0.000	0.000	.298	1.080	0.000	42.404	12.279	0.000
All Decapoda	2.270	.662	0.000	0.000	.090	.155	.144	.316	.131	0.000
All Calanoida	782.569	1167.961	1.201	.204	284.332	158.188	49.480	90.482	145.104	.224
All Hyperiidae	2.956	4.077	0.000	0.000	11.942	2.256	0.000	11.878	1.883	0.000
All Gammaridae	.305	.309	0.000	0.000	4.906	3.239	0.000	2.204	5.263	0.000
All Echinoderms	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Isopoda	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Hydroids	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 1 (continued).

Date in August 1985		30	30	30	30	30	30	30	30	30
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal		1	2	2	2	3	2	2	2	1
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m		2	5	6.9	8.9	1	4.8	8.9	16.2	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water		1	1	1	1	1	1	1	1	1
Depth of thermocline (m)		6.25	6.25	6.25	6.25	5.5	5.5	5.5	5.5	5.5
Secchi depth (m)		2.6	2.6	2.6	2.6	1.8	1.8	1.8	1.8	1.8
Water depth (m)		21	21	21	21	40	40	40	40	40
	Sample number	53	54	55	56	57	58	59	60	61
Taxon	Cu. m filtered	101.91	196.34	209.3	213.94	208.99	207.81	219.15	197.91	197.76
All Zooplankton		290.277	42.083	89.236	220.990	1.627	10.947	138.585	82.630	100.832
All Hydrozoa		5.868	.458	12.738	3.071	.005	0.000	.698	6.831	8.940
All Ctenophora		.942	0.000	5.514	4.053	.062	0.000	.329	.086	.991
All Pteropoda		.265	0.000	.196	.855	0.000	0.000	1.118	.248	.162
All Chaetognatha		1.452	0.000	.860	.234	0.000	0.000	.876	2.840	2.892
All Larvaceans		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.020
All Pisces		14.248	36.447	20.253	5.595	.766	3.003	7.137	3.774	6.695
All Ostracoda		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Mysidacea		55.206	4.085	14.673	24.063	0.000	0.000	.913	.081	2.624
All Euphausiacea		.814	0.000	0.000	4.347	0.000	0.000	8.565	1.420	2.412
All Decapoda		.069	.056	.593	0.000	0.000	0.000	.265	.561	.607
All Calanoida		200.178	.421	31.132	164.427	.569	5.823	106.511	64.814	73.010
All Hyperiidae		9.479	0.000	.502	11.097	0.000	0.000	9.806	.470	1.193
All Gammaridae		.540	0.000	.330	1.155	0.000	1.949	1.501	1.501	.961
All Echinoderms		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Isopoda		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
All Hydroids		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 2. Numbers of major groups of zooplankton per cubic metre of water filtered.

Date in August 1985	23	23	23	23	23	23	25	25	25	25
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	1	1	1	2	1	3	1	1	1	1
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	1	1	1	6	2	1	1	1	1	2
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	2	2	1	1	1	1	1	1	2	2
Depth of thermocline (m)	4	3.5	6.25	6.25	3	4	4.5	4.5	4	5.5
Secchi depth (m)	4	3.7	3.4	3.4	3.1	1.8	1.4	1.4	2.3	3.4
Water depth (m)	171	157	81	81	12	6.5	131	131	39	17
Sample number	1	2	3	4	5	6	7	9	10	11
Taxon Cu. m filtered	90.12	111.42	102.19	191.28	56.06	198.37	12.62	18.47	132.72	81.35
All Zooplankton	72.48	30.73	70.27	278.90	175.31	37.67	33.12	142.39	59.76	1745.70
All Hydrozoa	.08	.07	.52	.69	0.00	0.00	0.00	2.71	3.68	1.91
All Ctenophora	.07	.06	.02	1.25	0.00	.01	0.00	.22	.14	.09
All Pteropoda	.19	.06	.03	.01	.18	0.00	.40	.81	1.43	2.53
All Chaetognatha	.81	.63	.64	.05	.39	.03	1.03	1.30	.26	.25
All Larvaceans	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Pisces	.01	.12	.04	.09	.02	0.00	0.00	.05	0.00	.01
All Ostracoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Mysidacea	.01	.31	.01	0.00	.07	0.00	0.00	.05	.06	.93
All Euphausiacea	0.00	0.00	0.00	.01	0.00	0.00	0.00	0.00	.01	.04
All Deacapoda	.01	.04	.08	.08	0.00	0.00	.16	.27	.05	.21
All Calanoida	71.11	29.37	68.72	275.37	174.46	37.63	30.98	136.87	53.29	1739.45
All Hyperiidae	.18	.08	.22	1.00	.07	0.00	.24	.11	.72	.11
All Gammaridae	.02	0.00	0.00	.03	.12	.01	0.00	0.00	.14	.18
All Echinoderms	0.00	0.00	0.00	0.00	0.00	0.00	.32	0.00	0.00	0.00
All Isopoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Hydroids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 2 (continued).

Date in August 1985		25	25	26	26	27	27	27	27	27	27
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal		3	3	3	3	1	3	2	3	2	3
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m		1	1	1	1	1	1	4.2	8	7.9	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water		3	3	3	3	1	1	1	1	1	1
Depth of thermocline (m)		5.5	9	0	0	7.5	7.5	7.5	7.5	5.75	5.75
Secchi depth (m)		2	.8	1.5	1.5	.9	.9	.9	.9	.9	.9
Water depth (m)		11	8	11	7	57	57	57	57	64	64
	Sample number	12	13	14	15	16	17	18	19	20	22
Taxon	Cu. m filtered	220.11	211.95	230.18	218.19	181.64	202.02	221.55	214.65	263.03	207.74
All Zooplankton		929.65	2463.21	792.89	1729.47	253.95	1.63	91.36	278.70	2959.83	2.41
All Hydrozoa		1.38	2.86	3.80	.35	.20	0.00	0.00	.24	.19	0.00
All Ctenophora		.08	.19	.08	.04	.02	0.00	0.00	.04	.23	0.00
All Pteropoda		.02	.71	.04	.02	.02	0.00	0.00	0.00	.00	0.00
All Chaetognatha		.00	.08	.30	.39	.36	0.00	0.00	.20	.02	0.00
All Larvaceans		.00	.01	.00	.01	0.00	0.00	0.00	0.00	0.00	0.00
All Pisces		0.00	.07	.06	.19	.06	0.00	0.00	.33	.47	0.00
All Ostracoda		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Mysidacea		.00	.05	0.00	.01	.07	0.00	0.00	.30	2.97	0.00
All Euphausiacea		0.00	0.00	0.00	0.00	.03	0.00	0.00	0.00	0.00	0.00
All Deacapoda		0.00	.04	0.00	0.00	.19	0.00	0.00	.86	1.07	0.00
All Calanoida		926.95	2459.15	788.53	1728.26	252.98	1.63	91.36	276.69	2954.86	2.41
All Hyperiidae		.00	.03	0.00	.04	.03	0.00	0.00	.04	.02	0.00
All Gammaridae		1.20	.02	.07	.16	0.00	0.00	0.00	.00	0.00	0.00
All Echinoderms		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Isopoda		0.00	0.00	0.00	0.00	.01	0.00	0.00	0.00	0.00	0.00
All Hydroids		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 2 (continued).

Date in August 1985	27	27	27	27	27	28	28	28	28	28
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	2	1	1	3	2	3	3	3	3	2
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	21.1	1	1	1	6.5	1	1	1	1	7.7
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	1	1	1	1	1	3	3	3	3	3
Depth of thermocline (m)	5.75	5.75	3.5	3.5	3.5	9	9	9	9	9
Secchi depth (m)	.9	.9	1.2	1.2	1.2	2.3	2.1	1.4	2.3	2.3
Water depth (m)	64	64	52	52	52	8	12	6.5	11.7	11.7
Sample number	23	24	25	26	27	28	29	30	31	32
Taxon Cu. m filtered	452.9	185.89	242.86	210.52	187.45	223.543	205.16	219.48	213.29	209.85
All Zooplankton	235.63	671.32	289.74	2.00	2231.81	2879.10	3185.03	4260.22	5196.59	3216.13
All Hydrozoa	3.77	1.55	1.05	0.00	6.20	.04	2.53	.59	9.76	11.13
All Ctenophora	.01	.17	0.00	0.00	.13	0.00	.04	0.00	.20	.07
All Pteropoda	0.00	.03	.00	0.00	1.85	0.00	0.00	0.00	0.00	0.00
All Chaetognatha	.36	.29	0.00	.00	.26	.42	.48	.96	1.46	2.04
All Larvaceans	0.00	0.00	0.00	0.00	0.00	.00	0.00	.00	.01	.00
All Pisces	.07	.06	0.00	0.00	.02	.02	0.00	0.00	0.00	.01
All Ostracoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Mysidacea	.19	.61	.04	0.00	.94	.62	0.00	.08	0.00	1.32
All Euphausiacea	.10	.06	0.00	0.00	.02	0.00	0.00	0.00	0.00	.04
All Deacapoda	.02	.10	.04	0.00	.03	.00	0.00	.00	0.00	.06
All Calanoida	230.76	668.27	288.56	1.98	2221.99	2877.87	3181.91	4258.50	5185.05	3201.07
All Hyperiidae	.33	.17	.03	.00	.33	.07	.02	.03	.07	.21
All Gammaridae	.01	.01	.00	0.00	.04	.06	.04	.05	.04	.17
All Echinoderms	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Isopoda	0.00	0.00	0.00	0.00	0.00	.00	0.00	0.00	0.00	0.00
All Hydroids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 2 (continued).

Date in August 1985	29	29	29	29	29	29	29	29	29	29
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	2	3	3	3	2	3	2	2	1	3
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	8.3	1	1	8.3	7.1	1	8.3	23.9	1	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	3	3	3	3	3	3	3	3	3	1
Depth of thermocline (m)	0	0	0	0	9	9	9	9	9	7.25
Secchi depth (m)	2.6	2.6	12	12	5.2	10.5	10.5	10.5	10.5	1.5
Water depth (m)	25	25	34	34	11	31	31	31	31	21
Sample number	33	34	35	36	37	38	39	40	41	42
Taxon — Cu. m filtered	220.86	227.97	212.63	213.64	201.22	222.58	205.04	342.69	216.52	221.56
All Zooplankton	5671.61	1695.11	11.18	342.03	1769.83	1.41	165.70	141.41	222.46	1215.72
All Hydrozoa	.95	.24	1.19	3.62	5.95	0.00	.22	6.43	3.25	.02
All Ctenophora	0.00	.01	.04	.07	.03	0.00	.04	.03	.03	0.00
All Pteropoda	.09	.16	.01	1.38	1.84	.01	1.39	.82	1.40	.01
All Chaetognatha	.66	.05	0.00	.19	.45	0.00	.05	.16	.09	.00
All Larvaceans	.01	0.00	.03	.15	.01	0.00	0.00	.00	0.00	0.00
All Pisces	.03	.00	0.00	0.00	.00	0.00	.01	0.00	0.00	.02
All Ostracoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Mysidacea	3.90	.08	0.00	.02	.40	0.00	.06	.07	.08	.13
All Euphausiacea	.05	0.00	0.00	.00	.09	0.00	.00	.37	.22	0.00
All Deacapoda	.11	0.00	0.00	.00	.00	0.00	.15	.02	.03	.01
All Calanoida	5665.71	1694.54	9.90	336.49	1759.51	1.38	163.56	133.35	217.25	1215.53
All Hyperiidae	.06	0.00	0.00	.10	1.51	0.00	.05	.08	.06	0.00
All Gammaridae	.05	.03	.01	.01	.01	.01	.16	.08	.06	0.00
All Echinoderms	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Isopoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Hydroids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 2 (continued).

Date in August 1985		29	29	30	30	30	30	30	30	30	30
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal		1	2	3	2	2	2	3	2	1	3
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m		2	8.6	1	4.4	8.3	18.1	1	8.3	1	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water		1	1	1	1	1	1	1	1	1	1
Depth of thermocline (m)		7.25	7.25	5.25	5.25	5.25	5.25	3	3	3	6.25
Secchi depth (m)		1.5	1.5	1.7	1.7	1.7	1.7	1.8	1.8	1.8	2.6
Water depth (m)		21	21	21	21	21	21	34	34	34	21
	Sample number	43	44	45	46	47	48	49	50	51	52
Taxon	Cu. m filtered	65.63	246.26	183.99	197.91	221.15	258.44	194.36	192.79	175.75	213.92
All Zooplankton		1864.67	2846.67	3.02	1.00	812.01	342.09	119.71	160.36	284.01	.52
All Hydrozoa		.27	.06	.01	0.00	.06	3.18	0.00	.60	.51	0.00
All Ctenophora		.06	.01	0.00	0.00	.64	.05	.03	.04	.02	0.00
All Pteropoda		2.15	2.18	.02	0.00	.04	1.77	.01	.04	.42	0.00
All Chaetognatha		.17	.15	0.00	0.00	.45	.27	0.00	.05	1.04	0.00
All Larvaceans		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.01	0.00
All Pisces		.09	.03	.04	.21	.16	.53	0.00	.01	.01	0.00
All Ostracoda		0.00	0.00	0.00	0.00	0.00	.25	0.00	0.00	0.00	0.00
All Mysidacea		3.95	1.89	0.00	0.00	.16	.27	1.08	.38	1.55	0.00
All Euphausiacea		.02	.01	0.00	0.00	.01	.02	0.00	.46	.19	0.00
All Decapoda		.17	.06	0.00	0.00	.01	.02	.01	.03	.01	0.00
All Calanoida		1857.69	2842.13	2.96	.79	809.44	335.30	118.54	158.43	280.03	.52
All Hyperiidae		.09	.13	0.00	0.00	.56	.12	0.00	.24	.07	0.00
All Gammaridae		.02	.02	0.00	0.00	.48	.30	0.00	.07	.15	0.00
All Echinoderms		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Isopoda		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Hydroids		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 2 (continued).

Date in August 1985		30	30	30	30	30	30	30	30	30
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal		1	2	2	2	3	2	2	2	1
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m		2	5	6.9	8.9	1	4.8	8.9	16.2	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water		1	1	1	1	1	1	1	1	1
Depth of thermocline (m)		6.25	6.25	6.25	6.25	5.5	5.5	5.5	5.5	5.5
Secchi depth (m)		2.6	2.6	2.6	2.6	1.8	1.8	1.8	1.8	1.8
Water depth (m)		21	21	21	21	40	40	40	40	40
	Sample number	53	54	55	56	57	58	59	60	61
Taxon	Cu. m filtered	101.91	196.34	209.3	213.94	208.99	207.81	219.15	197.91	197.76
All Zooplankton		462.14	1.76	70.61	331.02	1.27	15.46	133.04	74.72	76.04
All Hydrozoa		.17	.04	.48	.71	0.00	0.00	.02	1.81	2.44
All Ctenophora		.16	0.00	.29	.25	.00	0.00	.06	.02	.10
All Pteropoda		.03	0.00	.01	.10	0.00	0.00	.40	.31	.58
All Chaetognatha		.09	0.00	.08	.03	0.00	0.00	.05	.13	.23
All Larvaceans		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.01
All Pisces		.20	.45	.28	.07	.01	.05	.10	.08	.11
All Ostracoda		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Mysidacea		4.18	.23	.73	.88	0.00	0.00	.10	.01	.07
All Euphausiacea		.03	0.00	0.00	.11	0.00	0.00	.14	.02	.03
All Deacapoda		.01	.01	.08	0.00	0.00	0.00	.02	.05	.05
All Calanoida		457.03	1.03	68.61	328.17	1.26	15.40	131.85	72.03	72.17
All Hyperiidae		.23	0.00	.03	.64	0.00	0.00	.25	.11	.19
All Gammaridae		.03	0.00	.02	.07	0.00	.00	.04	.14	.07
All Echinoderms		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Isopoda		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All Hydroids		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 3. Biomass (mg) of calanoid copepods per cubic metre of water filtered.

Date in August 1985	23	23	23	23	23	23	25	25	25	25
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	1	1	1	2	1	3	1	1	1	1
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	1	1	1	6	2	1	1	1	1	2
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	2	2	1	1	1	1	1	1	2	2
Depth of thermocline (m)	4	3.5	6.25	6.25	3	4	4.5	4.5	4	5.5
Secchi depth (m)	4	3.7	3.4	3.4	3.1	1.8	1.4	1.4	2.3	3.4
Water depth (m)	171	157	81	81	12	6.5	131	131	39	17
Sample number	1	2	3	4	5	6	7	9	10	11
Taxon Cu. m filtered	90.12	111.42	102.19	191.28	56.06	198.37	12.62	18.47	132.72	81.35
All Calanoids (+ skeletons)	53.884	25.624	44.398	224.629	73.541	13.991	28.629	74.320	60.277	749.982
All Calanoids (- skeletons)	53.884	25.624	44.398	224.629	73.541	13.991	28.550	74.320	60.277	749.982
Calanoid skeletons	0.000	0.000	0.000	0.000	0.000	0.000	.079	0.000	0.000	0.000
Calanus hyperboreus	4.217	8.661	7.789	72.940	12.344	.262	5.785	9.978	31.465	18.095
Calanus glacialis	29.206	6.498	3.229	32.879	7.185	.403	8.819	16.286	8.635	19.816
Pseudocalanus minutus	.355	.072	.039	0.000	1.782	1.774	.238	.033	.143	.381
Derjuginia tolli	.111	.009	.029	0.000	.856	.015	.056	.162	0.000	0.000
Euchaeta glacialis	9.942	1.979	3.327	15.726	0.000	0.000	6.022	1.949	.964	0.000
Metridia longa	.621	0.000	.029	0.000	1.142	.040	.024	0.000	1.190	1.573
Acartia spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Limnocalanus macrurus	9.432	8.405	29.954	103.085	50.232	11.494	7.591	45.912	17.880	710.117
Chiridius obtusifrons	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eurytemora spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Centropages hamata	0.000	0.000	0.000	0.000	0.000	0.000	.016	0.000	0.000	0.000
Temoridae spp.	0.000	0.000	0.000	0.000	0.000	.002	0.000	0.000	0.000	0.000

Appendix 3 (continued).

Date in August 1985	25	25	26	26	27	27	27	27	27	27
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	3	3	3	3	1	3	2	3	2	3
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	1	1	1	1	1	1	4.2	8	7.9	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	3	3	3	3	1	1	1	1	1	1
Depth of thermocline (m)	5.5	9	0	0	7.5	7.5	7.5	7.5	5.75	5.75
Secchi depth (m)	2	.8	1.5	1.5	.9	.9	.9	.9	.9	.9
Water depth (m)	11	8	11	7	57	57	57	57	64	64
Sample number	12	13	14	15	16	17	18	19	20	22
Taxon Cu. m filtered	220.11	211.95	230.18	218.19	181.64	202.02	221.55	214.65	263.03	207.74
All Calanoids (+ skeletons)	434.555	1250.177	352.780	545.717	108.330	.569	39.358	119.003	1038.250	.991
All Calanoids (- skeletons)	434.555	1250.177	352.563	456.547	108.054	.549	39.315	119.003	958.442	.967
Calanoid skeletons	0.000	0.000	.217	89.170	.275	.020	.043	0.000	79.808	.024
Calanus hyperboreus	56.990	45.898	28.916	0.000	10.923	0.000	0.000	.522	19.465	.265
Calanus glacialis	1.899	0.000	.178	3.084	22.198	0.000	0.000	.745	31.145	.019
Pseudocalanus minutus	2.326	0.000	.452	.573	4.052	.003	0.000	0.000	.316	.001
Derjuginia tolli	0.000	0.000	0.000	0.000	.705	0.000	0.000	0.000	0.000	0.000
Euchaeta glacialis	0.000	0.000	0.000	0.000	2.995	0.000	0.000	0.000	0.000	0.000
Metridia longa	0.000	0.000	0.000	0.000	.237	0.000	0.000	0.000	0.000	0.000
Acartia spp.	0.000	0.000	0.000	0.000	0.000	0.000	.006	0.000	0.000	0.000
Limnocalanus macrurus	373.341	1204.279	323.017	452.890	66.946	.544	39.309	117.736	907.516	.674
Chiridius obtusifrons	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eurytemora spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Centropages hamata	0.000	0.000	0.000	0.000	0.000	.002	0.000	0.000	0.000	.003
Temoridae spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 3 (continued).

Date in August 1985	27	27	27	27	27	28	28	28	28	28
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	2	1	1	3	2	3	3	3	3	2
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	21.1	1	1	1	6.5	1	1	1	1	7.7
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	1	1	1	1	1	3	3	3	3	3
Depth of thermocline (m)	5.75	5.75	3.5	3.5	3.5	9	9	9	9	9
Secchi depth (m)	.9	.9	1.2	1.2	1.2	2.3	2.1	1.4	2.3	2.3
Water depth (m)	64	64	52	52	52	8	12	6.5	11.7	11.7
Sample number	23	24	25	26	27	28	29	30	31	32
Taxon Cu. m filtered	452.9	185.89	242.86	210.52	187.45	223.543	205.16	219.48	213.29	209.85
All Calanoids (+ skeletons)	100.283	265.668	86.264	.949	704.700	1125.059	1347.129	1782.673	2109.063	1330.717
All Calanoids (- skeletons)	100.283	265.668	4.035	.944	622.758	1074.670	1272.261	1773.487	2089.859	1298.999
Calanoid skeletons	0.000	0.000	82.228	.005	81.942	50.389	74.868	9.185	19.204	31.718
Calanus hyperboreus	15.120	15.149	.107	.189	21.851	11.452	26.204	0.000	0.000	31.718
Calanus glacialis	13.566	12.846	1.054	0.000	5.463	0.000	0.000	0.000	0.000	0.000
Pseudocalanus minutus	5.087	6.886	0.000	.001	0.000	2.975	3.241	.570	6.236	.396
Derjuginia tolli	.749	0.000	0.000	.001	0.000	2.085	0.000	0.000	0.000	.610
Euchaeta glacialis	2.967	7.402	.527	0.000	0.000	0.000	0.000	0.000	0.000	12.199
Metridia longa	0.000	.457	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Acartia spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Limnocalanus macrurus	62.793	222.928	2.347	.750	595.444	1058.159	1242.815	1772.918	2083.623	1254.077
Chiridius obtusifrons	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eurytemora spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Centropages hamata	0.000	0.000	0.000	.002	0.000	0.000	0.000	0.000	0.000	0.000
Temoridae spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 3 (continued).

Date in August 1985	29	29	29	29	29	29	29	29	29	29
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	2	3	3	3	2	3	2	2	1	3
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	8.3	1	1	8.3	7.1	1	8.3	23.9	1	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	3	3	3	3	3	3	3	3	3	1
Depth of thermocline (m)	0	0	0	0	9	9	9	9	9	7.25
Secchi depth (m)	2.6	2.6	12	12	5.2	10.5	10.5	10.5	10.5	1.5
Water depth (m)	25	25	34	34	11	31	31	31	31	21
Sample number	33	34	35	36	37	38	39	40	41	42
Taxon Cu. m filtered	220.86	227.97	212.63	213.64	201.22	222.58	205.04	342.69	216.52	221.56
All Calanoids (+ skeletons)	2251.675	688.231	3.918	153.206	781.120	.801	116.841	121.594	127.540	444.701
All Calanoids (- skeletons)	2005.945	674.755	3.806	153.206	781.120	.797	116.841	121.557	127.540	437.769
Calanoid skeletons	245.730	13.476	.113	0.000	0.000	.004	0.000	.037	0.000	6.933
Calanus hyperboreus	83.456	37.057	1.928	19.547	24.172	.105	27.156	44.448	24.977	0.000
Calanus glacialis	0.000	5.198	.031	5.172	5.089	.166	26.112	20.849	22.160	0.000
Pseudocalanus minutus	3.011	3.645	1.019	2.495	1.238	.013	.176	.216	.591	0.000
Derjuginia tolli	0.000	0.000	.009	0.000	0.000	0.000	0.000	.085	0.000	0.000
Euchaeta glacialis	0.000	0.000	.033	2.771	0.000	0.000	0.000	4.511	1.210	0.000
Metridia longa	0.000	0.000	.014	.398	2.545	0.000	0.000	3.825	.568	0.000
Acartia spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Limnocalanus macrurus	1919.478	628.855	.752	122.823	748.077	.512	63.397	47.623	78.034	437.769
Chiridius obtusifrons	0.000	0.000	.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eurytemora spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Centropages hamata	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Temoridae spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 3 (continued).

Date in August 1985	29	29	30	30	30	30	30	30	30	30
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	1	2	3	2	2	2	3	2	1	3
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	2	8.6	1	4.4	8.3	18.1	1	8.3	1	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	1	1	1	1	1	1	1	1	1	1
Depth of thermocline (m)	7.25	7.25	5.25	5.25	5.25	5.25	3	3	3	6.25
Secchi depth (m)	1.5	1.5	1.7	1.7	1.7	1.7	1.8	1.8	1.8	2.6
Water depth (m)	21	21	21	21	21	21	34	34	34	21
Sample number	43	44	45	46	47	48	49	50	51	52
Taxon Cu. m filtered	65.63	246.26	183.99	197.91	221.15	258.44	194.36	192.79	175.75	213.92
All Calanoids (+ skeletons)	782.569	1167.961	1.201	.204	284.332	158.188	49.480	90.482	145.104	.224
All Calanoids (- skeletons)	782.569	1093.113	.625	.168	264.653	157.797	49.419	90.482	145.104	.180
Calanoid skeletons	0.000	74.848	.576	.035	19.679	.391	.062	0.000	0.000	.044
Calanus hyperboreus	39.982	10.396	.004	0.000	4.630	12.877	.057	24.068	16.751	.009
Calanus glacialis	5.363	0.000	0.000	0.000	21.126	12.200	1.178	11.038	13.986	0.000
Pseudocalanus minutus	0.000	.674	.002	.002	0.000	.484	0.000	.270	.831	.002
Derjuginia tolli	0.000	0.000	0.000	0.000	0.000	.224	0.000	0.000	.165	0.000
Euchaeta glacialis	0.000	0.000	0.000	0.000	0.000	4.705	0.000	0.000	.728	0.000
Metridia longa	0.000	0.000	0.000	0.000	.579	3.765	0.000	0.000	2.669	0.000
Acartia spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Limnocalanus macrurus	737.224	1082.043	.620	.167	238.318	123.541	48.184	55.107	109.974	.168
Chiridius obtusifrons	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eurytemora spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Centropages hamata	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Temoridae spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 3 (continued).

Date in August 1985	30	30	30	30	30	30	30	30	30
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	1	2	2	2	3	2	2	2	1
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	2	5	6.9	8.9	1	4.8	8.9	16.2	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	1	1	1	1	1	1	1	1	1
Depth of thermocline (m)	6.25	6.25	6.25	6.25	5.5	5.5	5.5	5.5	5.5
Secchi depth (m)	2.6	2.6	2.6	2.6	1.8	1.8	1.8	1.8	1.8
Water depth (m)	21	21	21	21	40	40	40	40	40
Sample number	53	54	55	56	57	58	59	60	61
Taxon Cu. m filtered	101.91	196.34	209.3	213.94	208.99	207.81	219.15	197.91	197.76
All Calanoids (+ skeletons)	200.178	.421	31.132	164.427	.569	5.823	106.511	64.814	73.010
All Calanoids (- skeletons)	200.178	.403	30.674	164.427	.373	5.813	106.511	64.814	73.010
Calanoid skeletons	0.000	.017	.459	0.000	.196	.010	0.000	0.000	0.000
Calanus hyperboreus	3.140	0.000	.459	13.761	0.000	0.000	19.128	17.382	36.570
Calanus glacialis	13.031	0.000	3.249	19.146	0.000	0.000	37.819	27.980	10.687
Pseudocalanus minutus	0.000	.001	.076	.194	0.000	0.000	0.000	1.132	.566
Derjuginia tolli	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.124	.055
Euchaeta glacialis	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.007	.816
Metridia longa	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.645
Acartia spp.	.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Limnocalanus macrurus	184.006	.402	26.890	131.327	.373	5.813	49.564	18.190	22.671
Chiridius obtusifrons	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Eurytemora spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Centropages hamata	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Temoridae spp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 4. Numbers of calanoid copepods per cubic metre of water filtered.

Date in August 1985	23	23	23	23	23	23	25	25	25	25
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	1	1	1	2	1	3	1	1	1	1
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	1	1	1	6	2	1	1	1	1	2
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	2	2	1	1	1	1	1	1	2	2
Depth of thermocline (m)	4	3.5	6.25	6.25	3	4	4.5	4.5	4	5.5
Secchi depth (m)	4	3.7	3.4	3.4	3.1	1.8	1.4	1.4	2.3	3.4
Water depth (m)	171	157	81	81	12	6.5	131	131	39	17
Sample number	1	2	3	4	5	6	7	9	10	11
Taxon Cu. m filtered	90.12	111.42	102.19	191.28	56.06	198.37	12.62	18.47	132.72	81.35
All Calanoids (+ skeletons)	71.11	29.37	68.72	275.37	174.46	37.63	30.98	136.87	53.29	1739.45
All Calanoids (- skeletons)	71.11	29.37	68.72	275.37	174.46	37.63	30.98	136.87	53.29	1739.45
Calanoid skeletons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calanus hyperboreus	2.22	2.69	2.00	16.39	6.06	.10	2.93	6.28	6.39	9.44
Calanus glacialis	42.34	6.68	1.48	17.40	6.85	.44	8.24	13.43	2.89	8.65
Pseudocalanus minutus	1.86	.32	.39	0.00	23.97	10.93	2.14	.22	1.08	2.36
Derjuginia tolli	.36	.07	.16	0.00	4.00	.02	.08	.22	0.00	0.00
Euchaeta glacialis	.84	.29	.78	1.34	0.00	0.00	.48	.43	.36	0.00
Metridia longa	.67	0.00	.04	0.00	.57	.02	.08	0.00	.96	.79
Acartia spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limnocalanus macrurus	22.81	19.31	63.88	240.23	133.00	26.09	16.96	116.30	41.59	1718.21
Chiridius obtusifrons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eurytemora spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Centropages hamata	0.00	0.00	0.00	0.00	0.00	0.00	.08	0.00	0.00	0.00
Temoridae spp.	0.00	0.00	0.00	0.00	0.00	.02	0.00	0.00	0.00	0.00

Appendix 4 (continued).

Date in August 1985	25	25	26	26	27	27	27	27	27	27
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	3	3	3	3	1	3	2	3	2	3
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	1	1	1	1	1	1	4.2	8	7.9	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	3	3	3	3	1	1	1	1	1	1
Depth of thermocline (m)	5.5	9	v	0	7.5	7.5	7.5	7.5	5.75	5.75
Secchi depth (m)	2	.8	1.5	1.5	.9	.9	.9	.9	.9	.9
Water depth (m)	11	8	11	7	57	57	57	57	64	64
Sample number	12	13	14	15	16	17	18	19	20	22
Taxon Cu. m filtered	220.11	211.95	230.18	218.19	181.64	202.02	221.55	214.65	263.03	207.74
All Calanoids (+ skeletons)	926.95	2459.15	788.53	1728.26	252.98	1.63	91.36	276.69	2954.86	2.41
All Calanoids (- skeletons)	926.95	2459.15	787.42	1275.37	251.57	1.54	91.14	276.69	2569.44	2.29
Calanoid skeletons	0.00	0.00	1.11	452.89	1.41	.09	.22	0.00	385.42	.12
Calanus hyperboreus	32.57	9.66	6.67	0.00	7.93	0.00	0.00	.45	7.79	.02
Calanus glacialis	4.65	0.00	.56	2.35	13.57	0.00	0.00	.15	27.25	.00
Pseudocalanus minutus	13.96	0.00	2.78	3.52	34.88	.01	0.00	0.00	1.95	.00
Derjuginia tolli	0.00	0.00	0.00	0.00	1.76	0.00	0.00	0.00	0.00	0.00
Euchaeta glacialis	0.00	0.00	0.00	0.00	1.94	0.00	0.00	0.00	0.00	0.00
Metridia longa	0.00	0.00	0.00	0.00	.35	0.00	0.00	0.00	0.00	0.00
Acartia spp.	0.00	0.00	0.00	0.00	0.00	0.00	.07	0.00	0.00	0.00
Limnocalanus macrurus	875.78	2449.48	777.41	1269.50	191.15	1.51	91.07	276.10	2532.46	2.22
Chiridius obtusifrons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eurytemora spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.02
Centropages hamata	0.00	0.00	0.00	0.00	0.00	.01	0.00	0.00	0.00	.01
Temoridae spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 4 (continued).

Date in August 1985	27	27	27	27	27	28	28	28	28	28
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	2	1	1	3	2	3	3	3	3	2
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	21.1	1	1	1	6.5	1	1	1	1	7.7
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	1	1	1	1	1	3	3	3	3	3
Depth of thermocline (m)	5.75	5.75	3.5	3.5	3.5	9	9	9	9	9
Secchi depth (m)	.9	.9	1.2	1.2	1.2	2.3	2.1	1.4	2.3	2.3
Water depth (m)	64	64	52	52	52	8	12	6.5	11.7	11.7
Sample number	23	24	25	26	27	28	29	30	31	32
Taxon Cu. m filtered	452.9	185.89	242.86	210.52	187.45	223.543	205.16	219.48	213.29	209.85
All Calanoids (+ skeletons)	230.76	668.27	288.56	1.98	2221.99	2877.87	3181.91	4258.50	5185.05	3201.07
All Calanoids (- skeletons)	230.76	668.27	6.32	1.95	1659.32	2662.57	3002.22	4211.85	5060.23	3074.20
Calanoid skeletons	0.00	0.00	282.24	.03	562.67	215.30	179.68	46.66	124.83	126.87
Calanus hyperboreus	6.22	7.92	.26	.04	1.37	1.15	2.50	0.00	0.00	4.88
Calanus glacialis	11.87	8.26	.26	0.00	2.73	0.00	0.00	0.00	0.00	0.00
Pseudocalanus minutus	43.52	57.84	0.00	.01	0.00	18.32	19.96	3.50	38.41	2.44
Derjuginia tolli	2.26	0.00	0.00	.00	0.00	4.58	0.00	0.00	0.00	2.44
Euchaeta glacialis	.14	.69	.26	0.00	0.00	0.00	0.00	0.00	0.00	2.44
Metridia longa	0.00	1.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acartia spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limnocalanus macrurus	166.75	592.18	5.53	1.88	1655.23	2638.53	2979.76	4208.35	5021.82	3062.00
Chiridius obtusifrons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eurytemora spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Centropages hamata	0.00	0.00	0.00	.01	0.00	0.00	0.00	0.00	0.00	0.00
Temoridae spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 4 (continued).

Date in August 1985	29	29	29	29	29	29	29	29	29	29
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	2	3	3	3	2	3	2	2	1	3
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	8.3	1	1	8.3	7.1	1	8.3	23.9	1	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	3	3	3	3	3	3	3	3	3	1
Depth of thermocline (m)	0	0	0	0	9	9	9	9	9	7.25
Secchi depth (m)	2.6	2.6	12	12	5.2	10.5	10.5	10.5	10.5	1.5
Water depth (m)	25	25	34	34	11	31	31	31	31	21
Sample number	33	34	35	36	37	38	39	40	41	42
Taxon Cu. m filtered	220.86	227.97	212.63	213.64	201.22	222.58	205.04	342.69	216.52	221.56
All Calanoids (+ skeletons)	5665.71	1694.54	9.90	336.49	1759.51	1.38	163.56	133.35	217.25	1215.53
All Calanoids (- skeletons)	4821.88	1618.18	9.83	336.49	1759.51	1.32	163.56	133.16	217.25	1178.55
Calanoid skeletons	843.83	76.36	.08	0.00	0.00	.06	0.00	.19	0.00	36.97
Calanus hyperboreus	13.91	7.86	.88	8.31	8.91	.01	8.43	8.03	6.06	0.00
Calanus glacialis	0.00	2.25	.01	2.47	1.27	.04	8.12	7.28	8.28	0.00
Pseudocalanus minutus	18.55	22.46	6.96	27.56	7.63	.12	1.09	3.36	4.73	0.00
Derjuginia tolli	0.00	0.00	.02	0.00	0.00	0.00	0.00	.19	0.00	0.00
Euchaeta glacialis	0.00	0.00	.01	.37	0.00	0.00	0.00	.56	.89	0.00
Metridia longa	0.00	0.00	.01	.60	1.27	0.00	0.00	2.99	1.03	0.00
Acartia spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limnocalanus macrurus	4789.42	1585.61	1.92	297.17	1740.42	1.15	145.92	110.75	196.27	1178.55
Chiridius obtusifrons	0.00	0.00	.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eurytemora spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Centropages hamata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Temoridae spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 4 (continued).

Date in August 1985	29	29	30	30	30	30	30	30	30	30
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	1	2	3	2	2	2	3	2	1	3
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	2	8.6	1	4.4	8.3	18.1	1	8.3	1	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	1	1	1	1	1	1	1	1	1	1
Depth of thermocline (m)	7.25	7.25	5.25	5.25	5.25	5.25	3	3	3	6.25
Secchi depth (m)	1.5	1.5	1.7	1.7	1.7	1.7	1.8	1.8	1.8	2.6
Water depth (m)	21	21	21	21	21	21	34	34	34	21
Sample number	43	44	45	46	47	48	49	50	51	52
Taxon Cu. m filtered	65.63	246.26	183.99	197.91	221.15	258.44	194.36	192.79	175.75	213.92
All Calanoids (+ skeletons)	1857.69	2842.13	2.96	.79	809.44	335.30	118.54	158.43	280.03	.52
All Calanoids (- skeletons)	1857.69	2721.55	1.93	.70	693.68	333.32	118.21	158.43	280.03	.50
Calanoid skeletons	0.00	120.59	1.02	.09	115.76	1.98	.33	0.00	0.00	.02
Calanus hyperboreus	13.65	14.55	.01	0.00	5.79	7.18	.08	13.20	8.19	.00
Calanus glacialis	2.93	0.00	0.00	0.00	10.42	9.66	.41	4.81	7.10	0.00
Pseudocalanus minutus	0.00	4.16	.01	.01	0.00	2.97	0.00	1.66	5.83	.01
Derjuginia tolli	0.00	0.00	0.00	0.00	0.00	.50	0.00	0.00	.36	0.00
Euchaeta glacialis	0.00	0.00	0.00	0.00	0.00	.50	0.00	0.00	.36	0.00
Metridia longa	0.00	0.00	0.00	0.00	.29	2.48	0.00	0.00	1.46	0.00
Acartia spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limnocalanus macrurus	1841.11	2702.83	1.91	.69	677.19	310.04	117.72	138.76	256.73	.48
Chiridius obtusifrons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eurytemora spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Centropages hamata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Temoridae spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 4 (continued).

Date in August 1985	30	30	30	30	30	30	30	30	30
Tow type: 1=oblique 2=horizontal at depth 3=surface horizontal	1	2	2	2	3	2	2	2	1
Tow depth (m). For oblique tows, 1= 0-25m, 2=0-10m	2	5	6.9	8.9	1	4.8	8.9	16.2	1
Surface water type: 1=diffuse plume, 2=mixed plume/Arctic water, 3=Arctic water	1	1	1	1	1	1	1	1	1
Depth of thermocline (m)	6.25	6.25	6.25	6.25	5.5	5.5	5.5	5.5	5.5
Secchi depth (m)	2.6	2.6	2.6	2.6	1.8	1.8	1.8	1.8	1.8
Water depth (m)	21	21	21	21	40	40	40	40	40
Sample number	53	54	55	56	57	58	59	60	61
Taxon — Cu. m filtered	101.91	196.34	209.3	213.94	208.99	207.81	219.15	197.91	197.76
All Calanoids (+ skeletons)	457.03	1.03	68.61	328.17	1.26	15.40	131.85	72.03	72.17
All Calanoids (- skeletons)	457.03	1.02	68.46	328.17	1.10	15.40	131.85	72.03	72.17
Calanoid skeletons	0.00	.01	.15	0.00	.16	0.00	0.00	0.00	0.00
Calanus hyperboreus	.31	0.00	.11	3.29	0.00	0.00	4.23	8.89	8.58
Calanus glacialis	6.44	0.00	1.83	6.28	0.00	0.00	10.81	11.72	5.83
Pseudocalanus minutus	0.00	.01	.15	1.20	0.00	0.00	0.00	7.36	4.21
Derjuginia tolli	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.32	.16
Euchaeta glacialis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.16	.40
Metridia longa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.54
Acartia spp.	.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Limnocalanus macrurus	449.65	1.02	66.35	317.40	1.10	15.40	116.81	43.58	51.46
Chiridius obtusifrons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eurytemora spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Centropages hamata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Temoridae spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 5. Biomass (mg/sample) of taxa collected in drop net samples at four stations off the Yukon coast, August 1985.

	Station 1 (N = 9)		Station 5 (N = 9)		Station 11 (N = 9)		Station 7 (N = 1)	All stations (N = 28)	
Taxon	Mean	SD	Mean	SD	Mean	SD	Mean	Mean	SD
unidentified fragments	-	-	-	-	2.6	5.3	-	.8	3.1
Hydrozoa	2.1	2.8	5.6	7.2	2.4	3.3	1.0	3.3	4.8
Aglantha digitale	2.1	2.8	5.6	7.2	1.8	3.0	1.0	3.1	4.8
Aeginopsis laurenti	-	-	-	-	.7	1.0	-	.2	.6
Ctenophora	-	-	.1	.3	6.0	18.0	-	1.9	10.2
Beroe cucumis	-	-	-	-	6.0	18.0	-	1.9	10.2
Cydippida spp.	-	-	.1	.3	-	-	-	<0.1	.2
Chaetognatha	13.8	14.8	12.9	22.3	22.8	28.2	52.0	17.8	22.6
Eukrohnia hamata	.3	1.0	.6	1.3	.6	1.7	6.0	.7	1.7
Sagitta elegans	13.4	14.2	12.3	21.4	22.2	27.3	46.0	17.1	21.6
Pisces	-	-	2.2	6.7	-	-	-	.7	3.8
Liparidae	-	-	2.2	6.7	-	-	-	.7	3.8
Mysidacea	38.8	30.8	69.2	43.0	23.7	25.6	243.0	51.0	52.9
Mysis litoralis	38.4	31.2	69.2	43.0	23.7	25.6	243.0	50.9	53.0
Mysid spp.	.3	1.0	-	-	-	-	-	.1	.6
Calanoida	57.8	17.7	51.9	21.9	42.7	48.0	135.0	53.8	34.8
Harpacticoida	-	-	-	-	.1	.3	-	<0.1	.2
Hyperiidae	-	-	.6	.9	-	-	-	.2	.6
Parathemisto abyssorum	-	-	.6	.9	-	-	-	.2	.6
Gammaridea	48.7	69.6	16.7	25.8	2.9	5.3	-	22.0	45.0
Apherusa glacialis	1.3	2.8	.9	2.0	1.1	2.4	-	1.1	2.3
Onisimus glacialis	2.3	7.0	2.8	5.2	-	-	-	1.6	4.9
Oedicerotidae	45.0	69.8	13.0	22.7	1.8	5.0	2.0	19.3	44.2
Polychaeta	-	-	7.9	15.9	-	-	-	2.5	9.4
Isopoda	-	-	-	-	665.2	742.9	-	213.8	513.4
Saduria entomon	-	-	-	-	665.2	742.9	-	213.8	513.4
Cumacea	2.0	4.0	-	-	-	-	18.0	1.3	4.0
All taxa	163.1	75.5	167.0	44.7	768.3	725.7	451.0	369.2	489.4